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EOS

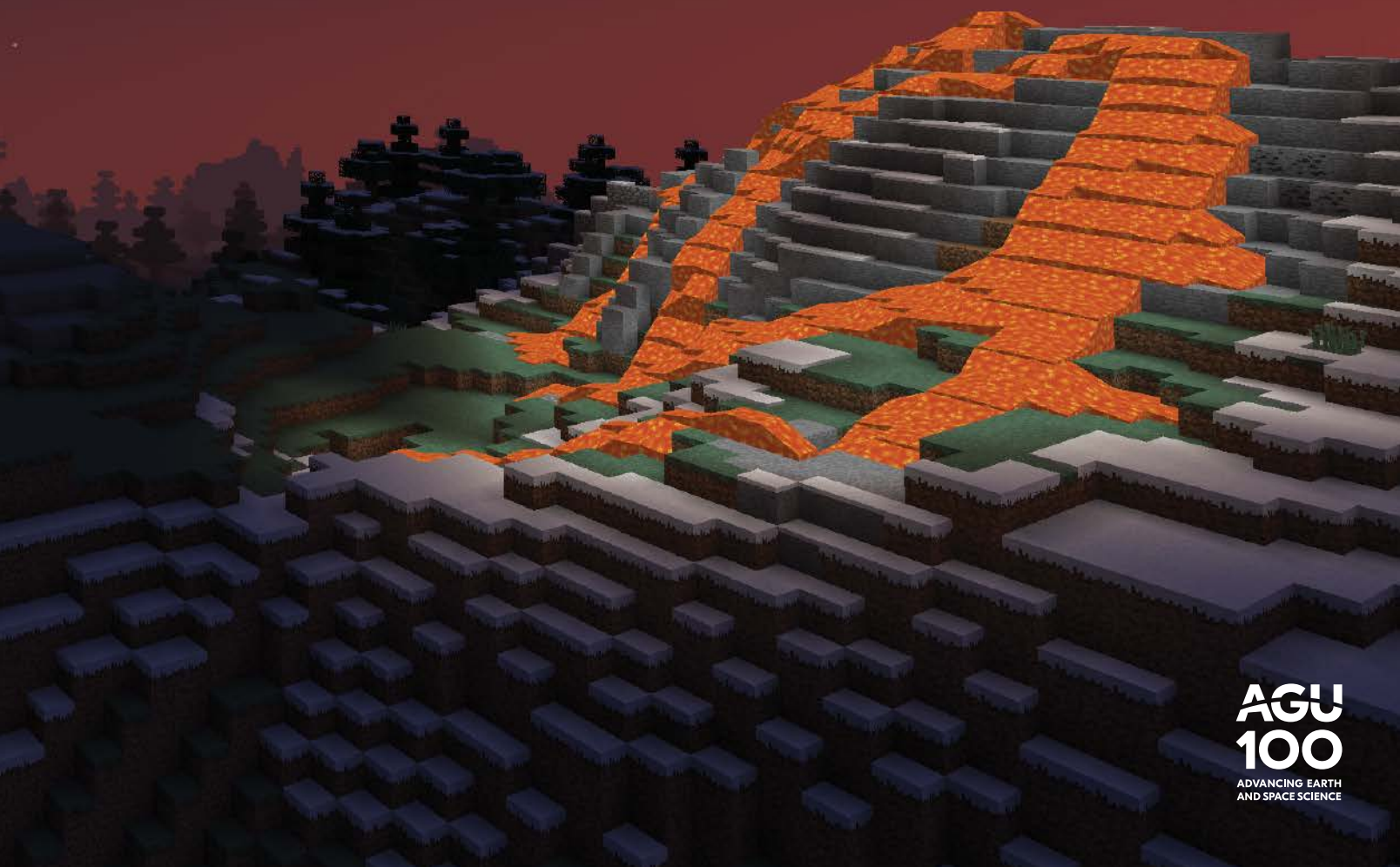
Earth & Space Science News

Eclipse Data May Help Weather Forecasting

Tracking Illegal Seafood With Satellites

Raising a Tantrum About Climate Change

DIG INTO GEOSCIENCE WITH MINECRAFT



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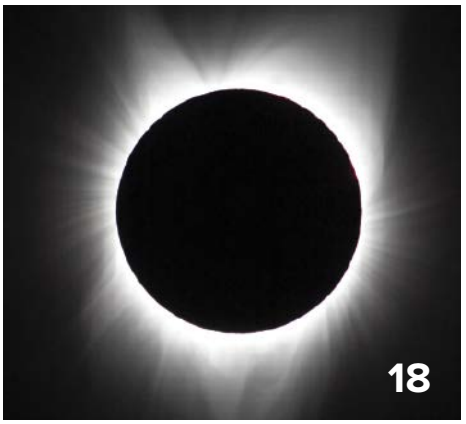
COVER

Digging Deep into Geosciences with Minecraft

Building volcanoes, caves, and other features in an "open-world" computer game can be an engaging way to teach the next generation about geoscience.

PROJECT UPDATE



Great American Eclipse Data May Fine-Tune Weather Forecasts

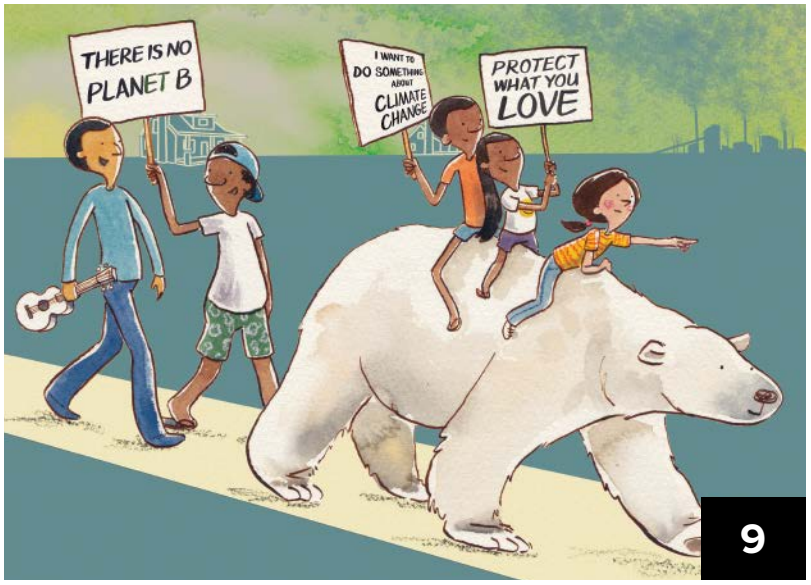
Measurements taken by an automated national meteorological monitoring network during the 2017 total solar eclipse illuminate how the land and atmosphere respond to a sudden loss of sunlight.

PROJECT UPDATE

Exploring the Unknown: The Ross Sea in Sea Ice–Free Conditions

A team of polar scientists aboard the *OGS Explora,* cruising in rare ice-free conditions, discovered new evidence of ancient and modern-day ice sheet sensitivity to climatic fluctuations.

DEPARTMENTS



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Christine W. McEntee, Executive Director/CEO

AGU 100 ADVANCING EARTH AND SPACE SCIENCE

Illegal Seafood Supply Chains Can Now Be Tracked by Satellite

Greenpeace, a nongovernmental organization devoted to combating environmental problems, flagged this particular transshipment, which took place off the western coast of Africa on 22 March 2017, as one that involved illegally caught fish. Credit: © Pierre Gleizes/Greenpeace

Fishing is an enormous industry—topping $100 billion per year—but waters often turn murky when it comes to determining where exactly fish are caught. That's because illegal catches are frequently moved at sea from fishing boats onto cargo vessels, a transfer known as a transshipment that can mask the dubious provenance of seafood.

Now researchers have pinpointed more than 10,000 likely transshipments by mining billions of ship positions recorded over 6 years. The analysis reveals transshipment "hot spots" near Russia and West Africa, results that can help maritime officials target patrol efforts, the scientists suggest.

Money Laundering at Sea

Offloading seafood onto refrigerated cargo ships at sea allows fishing vessels to remain in prime fishing areas, which saves time and fuel. "The transshipment of fish catches at sea plays a big role in the seafood supply chain," said Kristina Börder, a biologist at Dalhousie University in Nova Scotia, Canada, and the leader of the new study, which was published last month in *Science Advances* (http://bit.ly/fish-transshipment).

But the practice of transshipment can also function like money laundering by hiding the true origin of potentially illegal catches, said Börder. Research has shown that more than 25% of wild-caught seafood in major markets is caught illegally, in violation of laws regarding fish caught in protected areas, catches obtained without a license, and the use of prohibited fishing gear.

To identify these aquatic rendezvous, Börder and her collaborators analyzed more than 22 billion position signals from ships. The data, collected via satellite between 2012 and 2017, are part of the automatic identification systems required by the International Maritime Organization on all ships larger than 300 metric tons engaging in international voyages.

Ships' position signals do more than just pinpoint the presence of a ship at a specific location. They also record each ship's speed, course, and type (fishing vessel, cargo vessel, etc.). A ship's information is collected every few seconds, and vessel positions are determined to within about 10 meters. It's the maritime equivalent of air traffic control.

Börder and her colleagues looked for likely transshipments by flagging close, prolonged encounters between a fishing vessel and a refrigerated cargo vessel. They found 10,510 such events, 65% of which took place within the exclusive economic zones near coastlines where most fishing occurs. By coupling known information on the fishing vessels' gear type with the tracked locations, the scientists inferred that tuna, swordfish, and marlin were among the most commonly transshipped species.

Hot Spots and Flags of Convenience

The researchers found intriguing patterns in their data. Likely transshipments tended to cluster geographically, with the highest concentrations occurring in waters near Russia and West Africa, Börder and her colleagues reported. The scientists also showed that ships registered in Russia, China, and Taiwan engaged in the most transshipments. Finding China on that list wasn't a surprise, Börder remarked. "China is responsible for 40% of the international fishing effort," she said. "That's more than the next 10 countries combined."

Börder and her collaborators also noted that vessels registered under so-called flags of convenience tended to be overrepresented in transshipments. Several countries, like Panama and Liberia, are known for loose maritime regulations. Shipowners who choose to register their vessels in such countries can be assured that oversight of their fleets will be limited. More than 40% of cargo vessels engaged in transshipments were represented by flags of convenience.

This study provides a "very good visual snapshot of hot spots," said Pramŏd Ganapathiraju, a fisheries compliance and illegal fishing consultant at IUU Risk Intelligence in Vancouver, B. C., who was not involved in the research. It's a neat demonstration of using abundant satellite data to track transshipments rather than relying on having maritime officials on board ships, he added.

More Than Just Fishing

The researchers note that their work is more than simply identifying where seafood is being transferred. Transshipments not only allow fishing vessels to offload their catch, but they also provide fishing vessels with such supplies as food and fuel. The latter transfers mean that fishing boats can remain at sea for long periods of time.

"Workers are on vessels for years and years on end, often in questionable circumstances," said Börder. For example, the Associated Press has reported that wages on board ships can be deplorably low or nonexistent, meaning that crew are essentially slaves. The United Nations has also found evidence that workers have been forced to engage in weapons or drug trafficking.

In response to the recent research, Börder's team was contacted by an organization in Thailand that focuses on links between transshipments and human rights abuses.

"This goes beyond the fish," she said.

By **Katherine Kornei** (email: hobbies4kk@gmail.com; @katherinekornei), Freelance Science Journalist

Landslide Database Reveals Uptick in Human-Caused Fatal Slides

This landslide, triggered by the weight of construction debris atop a rain-saturated hillslope, killed 73 people in China in 2015. The landslide originated on the hill in the foreground. Credit: VCG/Visual China Group/Getty Images

In 2015, a landslide in China's Guangdong province swept more than 70 people to their death. Triggered by heavy rains that saturated the soil under a pile of construction waste that had been precariously perched on a hillside for more than 2 years, the landslide rushed through an office park in the city of Shenzhen. It crushed office buildings, enveloping them in mud up to 11 meters deep in a debris field that spanned an area roughly the size of 70 football fields.

This event does more than highlight the deadly nature of landslides, hundreds of which occur every year around the world. It brings into focus an emerging new class of landslides: those triggered by human activities.

Researchers now have an idea of how many such landslides are occurring around the globe. They have compiled the most comprehensive database of landslides that took place between 2004 and 2016. This database includes information on the landslides' causes as well as their death toll.

The records reveal an uptick in the frequency of human-caused fatal slides, a worrying trend given the increasing prevalence of landslide-causing activities such as construction, illegal mining, and hill cutting.

> "Competition for land forces the poorest members of society to occupy steep, unstable slopes."

Nearly 5,000 Landslides

Melanie Froude, a geographer, and David Petley, an Earth scientist, both at the University of Sheffield in the United Kingdom, assembled the database from reports of fatal landslides. The researchers tabulated 4,862 distinct landslides, which were responsible for, in total, 55,997 deaths, they reported in a paper published in *Natural Hazards and Earth System Sciences* on 23 August (http://bit.ly/NHESS-landslides).

"Collecting these reports and organizing them into a database shows us where landslides are frequently harming people, what causes these landslides, and whether there are patterns in fatal landslide occurrence over time," Froude told *Eos*.

An alarming trend stood out in the data: More than 700 of the landslides could be linked directly to human activities like construction, illegal mining, and hill cutting. These landslides were responsible for a total of 3,725 deaths.

What's more, the prevalence of landslides with human fingerprints has increased by several percent, on average, each year since 2006.

Unstable Slopes Spell Disaster

The scientists also found that landslides were unevenly distributed geographically: More than 75% of landslides occurred in Asia. "The combination of tectonics and climate in Asia creates extremely active landscapes," Froude said.

Mountainous regions in Asia are particularly susceptible to landslides, she added. "As settlements expand to accommodate more residents, competition for land forces the poorest members of society to occupy steep, unstable slopes."

And as more people live in steeper areas, the more likely it is that their behaviors will influence the stability of the slopes around them, the researchers explained.

Froude and Petley found unsurprisingly that the overall frequency of landslides was correlated with rainfall. For instance, landslides were more frequent in Southeast Asia during the summer monsoon season. However, the researchers noted that more data need to be collected before it will be possible to potentially link landslide incidence with climate change trends.

"This article is an important contribution to quantifying the scope of landslide impacts around the world," said Jonathan Godt, a landslide scientist with the U.S. Geological Survey in Golden, Colo., who was not involved in the research.

Research, Regulations, Education

Froude and Petley plan to release their database online in the coming months. They've already created a map showing where landslides in their database have occurred (http://bit.ly/Froude-landslide-map).

Froude highlights that additional research, regulations, and education will be useful for preventing future human-caused landslides. "We need to refocus our efforts globally on preventable slope accidents," she said.

By **Katherine Kornei** (email: hobbies4kk@gmail.com; @katherinekornei), Freelance Science Journalist

Dinosaur-Killing Asteroid Impact Made Huge Dead Zones in Oceans

About 66 million years ago, an asteroid roughly 10 kilometers wide hit Earth in what is today the Gulf of Mexico. It brought annihilation: All the dinosaurs except for the birds went extinct; forests around the planet vanished temporarily, killing off all bird species that lived in trees; dust and other aerosols blocked the Sun; and global temperatures took a nosedive. The world plunged into a state analogous to nuclear winter.

Another effect of the impact, according to new work, was a depletion of oxygen in the oceans triggered by rapid global warming following the nuclear winter–like state. Such anoxia, the researchers behind the work report, devastated marine life. What's more, this episode of anoxia may have parallels to the rapid global warming and resulting ocean anoxia being wrought by human-driven climate change today.

"The global warming following the impact is one of the most rapid warmings in Earth's history," said Johan Vellekoop, a geologist at KU Leuven in Belgium who led the new research. "It's on a human timescale." He said that the postimpact warming happened over the course of only a few hundred to a few thousand years.

By comparison, humans have been injecting carbon dioxide (CO_2) into the atmosphere—and driving global warming in the process—for about 200 years, since the start of the Industrial Revolution. Vellekoop and his team note in a paper published in *Geology* in June (http://bit.ly/asteroid-anoxia) that as today's warming continues unabated, the oceans appear poised to become anoxic once again.

An Unlucky Day

When the asteroid struck, it hit a platform of carbonate rock that was about 3 kilometers thick, creating a feature called the Chicxulub crater. Carbonate rock, when vaporized by something like a giant asteroid, releases CO_2 into the atmosphere; previous work estimates that the amount of CO_2 injected into the air after the impact equaled about 1,400 gigatons. By comparison, humans injected roughly 32.5 gigatons of CO_2 into the atmosphere in 2017 alone.

After the impact, a state akin to nuclear winter descended, which saw global average temperatures fall by about 25°C, explained Timothy Bralower, a marine geologist at Pennsylvania State University who was not involved in the new research. The winter probably lasted for only a few years, and then as the dust cleared, global warming got going and sea surface temperatures climbed by 1.5°C–2°C.

And Then There Was Anoxia

For their study, Vellekoop and his team visited three Northern Hemisphere sites in Texas, Denmark, and Spain and took samples of marine rocks from strata right above the asteroid impact horizon. They tested the rocks for concentrations of the element molybdenum; "we found enrichments of molybdenum, which are indicators of low oxygen conditions," said Vellekoop.

When oxygen is plentiful, it binds to molybdenum and removes it from seawater, he explained. When oxygen is scant, molybdenum sticks around in the seawater, where it can then be incorporated into rocks like the ones the team tested. In rocks from Denmark, for instance, molybdenum concentrations jump from 1 or 2 parts per million to "up to 100 parts per million in the layer directly above the impact," Vellekoop said.

This increase suggests that ancient shallow oceans were relatively warm places, Bralower explained, because warmer ocean waters have a harder time retaining dissolved oxygen than colder waters. In such a world, there are oxygen dead zones where oxygen is scant or completely absent.

During postimpact warming, explained Vellekoop, dead zones would have helped devastate marine ecosystems, especially shallow-water seafloors where creatures like corals and bivalves dwelled. Such coastal waters "are the places with the highest diversity," he said.

A Mirror in the Past

In the course of geologic events, many things tend to happen on relatively long timescales. But an asteroid impact is an exception. It is, by definition, instantaneous.

Such rapidity, explained Ellen Thomas, a paleoceanographer at Yale University who was not involved in the work, makes this ancient warming analogous to today's human-driven global warming, which is close to being as quick as asteroid-related warming. "Although the causes are slightly different and the timescale may be different, the basic principles are the same," she said.

Life can adapt in the face of such change, Thomas added, but how much it is able to do so depends on the rate of change. Basically, "the slower the change, the better it is for life," she said.

Today, because some areas of the oceans are already showing signs of oxygen depletion, the threat is not as much from off planet as it is from within, Thomas explained. Thus, if temperatures continue to climb in the coming century, humanity seems poised to become its own kind of asteroid.

Artist's rendering of an asteroid more than 10 kilometers wide striking Earth about 66 million years ago. Credit: Mark Garlick/Science Photo Library/Getty Images

By **Lucas Joel** (email: lucasvjoel@gmail.com), Freelance Writer

Severe Drought May Have Helped Hasten Ancient Maya's Collapse

El Castillo (also called the Temple of Kukulcan), a pyramid in the ancient Maya city of Chichén Itzá. The structure is on the Yucatán Peninsula in Mexico. Credit: iStock.com/oneinchpunch

For centuries, the Maya people relied on rain to keep them alive. But then, suddenly, the skies went dry. At least, that's what the latest research suggests.

From about 250 to 900 CE, the Maya civilization thrived during what's known as its Classic period. During this time, the Maya built cities with plazas and multistory temples, devised a complex calendar system, and housed an urban population density that rivals Los Angeles County today.

But then, sometime between the 8th and 9th centuries, many of the bustling Maya cities fell silent. By around 900 CE, a number of the grand cities had been abandoned.

Scholars have many theories about what went wrong. Some speculate that deforestation drove people away; others believe that wars and political strife tore cities apart. Still more note that the whole idea of a collapse is too simplistic because not all Maya cities fell, and some were reinhabited. The jury is still out because none of the hypotheses can fully explain what caused a society advanced enough to conceptualize the number zero and potentially predict meteor showers to crumble.

A study published on 3 August in *Science* (http://bit.ly/Maya-drought) offers fodder for another answer: a severe drop in rainfall that coincided with the Maya downfall.

At the end of the Classic period in the northern reaches of the Maya civilization, "rainfall decreased, on average, by about half and up to 70% during peak drought conditions," lead author Nick Evans, a Ph.D. candidate at the University of Cambridge, told *Eos*. Given the finding, "our research provides another piece of the puzzle for understanding the Maya collapse," he said.

A Rain Forest in Drought

The Maya people lived in the lush rain forests throughout what's mostly now Guatemala, Belize, and southeastern Mexico. Scholars believe that the Maya relied heavily on rain to fuel their maize fields and fill reservoirs.

But past research indicated that the humid ecosystem of the northern rain forests, near population centers like Chichén Itzá and Uxmal, may have withered. Previously published paleoclimate data gleaned from proxies within lake cores on the Yucatán Peninsula revealed that a drought befell the area during 800–1000 CE (see http://bit.ly/paleoclimate-data).

"Rainfall decreased, on average, by about half and up to 70% during peak drought conditions."

However, the magnitude of this drought remained unclear, the authors note in their paper. Was it a mild shift toward less precipitation or an intense dry spell?

To find out more, researchers examined the same lake as in the prior study: Lake Chichancanab, a body of salty water that lies in the northern Yucatán.

Hydrogen and oxygen atoms, the researchers hypothesized, hold the key to understanding the drought.

Water, Trapped in Crystals

Within Lake Chichancanab, the authors looked at stable isotopes in gypsum, a soft sulfate mineral. Normally, gypsum is dissolved in the lake's water. But if the lake shrinks—because of, say, a drought—the gypsum reaches saturation and starts raining out as a solid onto the lake bed. The prior paleoclimate data, among other findings, pointed to the mere presence of gypsum in the sediment record as evidence of drought.

But the new study goes a step further. Gypsum is a hydrous mineral, meaning that it has two water molecules bound in its crystalline structure. When gypsum precipitates out from the lake waters, it takes with it several hydrogen and oxygen atoms, capturing in its crystals the characteristics of the lake water from which it formed. These hydrogen and oxygen atoms, the researchers hypothesized, hold the key to understanding the drought.

Oxygen (O) has several types of naturally occurring isotopes. Each isotope has only eight protons in its nucleus but has different numbers of neutrons. The lightest of the bunch, ^{16}O, is the most easily evaporated because it has the fewest neutrons. The heavier oxygen isotopes, ^{18}O and ^{17}O, are more likely to stay behind and not evaporate. The same applies for hydrogen's stable isotopes.

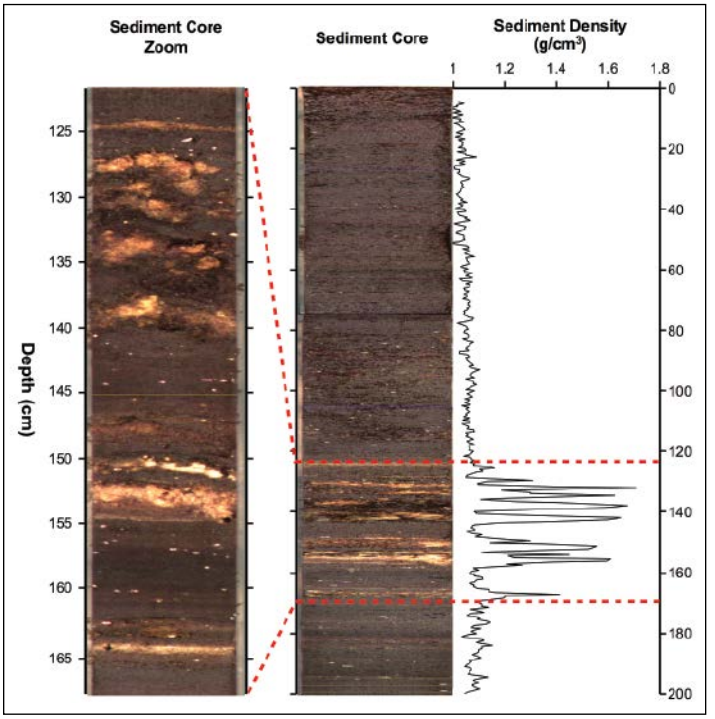
During a severe dry spell, Lake Chichancanab would have suffered from increased evaporation, meaning that over time, evaporation "enriches the lake in the heavier isotopes of hydrogen and oxygen in water," the authors write. Did this enrichment happen during the previously identified drought?

The Heavy Isotopes' Tale

The researchers checked the gypsum from Lake Chichancanab sediment cores collected in a prior study and found just that: Heavier oxygen and hydrogen isotopes appeared in higher concentrations during times of suspected drought compared with the isotope ratios in modern-day lake waters. From 750 to 1050 CE, intermittent droughts likely plagued the region, specifically around 750–850 CE and 950–1050 CE.

The researchers then simulated how bad the drought would have been to result in the isotope ratio seen in the gypsum. The simulations gave a stark number: Precipitation in the area had likely dropped to 50% of its predrought level. During the worst of the drought, precipitation may have even plummeted to 30% of its predrought level.

"Prior results pointed to more modest reductions in rainfall," Evans told *Eos*, "but our new methodology using all stable isotopes in water reveals that the droughts in northern Yucatán were more severe than previously thought."



Sediment core from the Yucatán's Lake Chichancanab. Dense layering indicates drier periods and spans the time that scholars believe to be the fall of the Maya civilization. Light-colored layers in the strata indicate gypsum crystals, which tend to precipitate during times of drought. Credit: Hodell et al., *2005, https://doi.org/10.1016/j.quascirev.2004.10.013*

Many Questions Remain

How do the new insights shape our understanding of the Maya collapse?

"The next step," said Evans, "is for agronomists to use this information in crop simulation models to predict the impact drought had on Maya agriculture." He also hopes that archaeologists studying ancient Maya's collapse will incorporate these results to better explain the cultural transformation that must have occurred when the rains stopped.

But Daniela Triadan, an anthropologist at the University of Arizona who focuses on Maya culture and was not involved in the research, cautioned against applying the results in this study to all of the Maya civilization. For example, she noted that cores from lakes to the south of the Yucatán don't show signs of drought.

Thus, at more southern Maya sites like Tikal and Seibal, "we have abandonments of settlements with no noticeable [population] returns occurring over a period of about 100 years," she said. "This is incidentally what people call the Maya 'collapse.' And interestingly, in the Yucatán, where we do have evidence for drought—and this paper makes an excellent case—we do not have permanent abandonments. So, clearly, other factors also play a role."

She added, "I think we need to be careful not to make this a single-factor narrative."

A Lesson for Today?

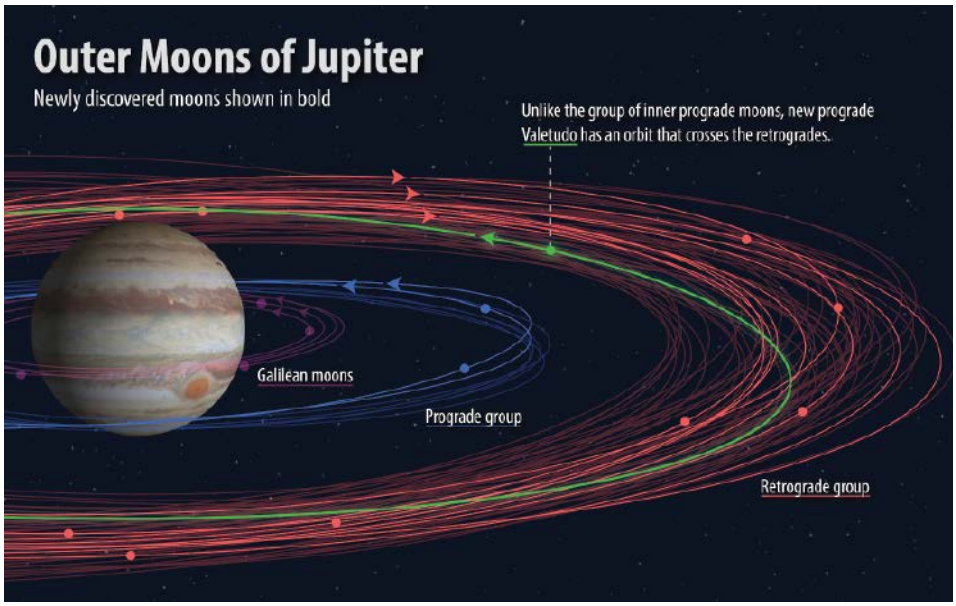
If drought did help lead to the Maya downfall, could it be an alarm bell for severe droughts that humans face today? Evans said that there "are no direct parallels" between the Maya drought his team documented and today's world because of the modern invention of genetically modified organisms (GMOs), drought-resistant plants, and transportation systems to redistribute water and food during shortages.

But, he said, "in an abstract sense, there are lessons to be learned about the sensitivity and resilience of society to climate change."

Takeshi Inomata, an archaeologist at the University of Arizona who focuses on the Maya and was not involved in the new study, agrees. "Climate change does not lead automatically to societal collapse. Depending on how society copes with environmental changes, outcomes can be very different," he said. "As we try to deal with climate change in the future, [archaeological] studies need to focus more on how past societies like the Maya coped with natural disasters successfully or unsuccessfully."

By **Jenessa Duncombe** (@jenessaduncombe), News Writing and Production Intern

Ten New Moons Discovered Around Jupiter



The 12 newly surveyed moons of Jupiter include two with inner prograde orbits (blue), nine with outer retrograde orbits (red), and one with an odd outer prograde (green). The orbits of the new moons are marked with thicker curves. Credit: Roberto Molar-Candanosa, courtesy of Carnegie Institution for Science

Jupiter's tally of moons is now a bit larger. A team of astronomers announced on 17 July the discovery of 10 additional moons orbiting the largest planet in our solar system, raising Jupiter's moon total to 79 (see http://bit.ly/new-jovian-moons).

The same survey that discovered these 10 also resurveyed two other moons previously discovered by the researchers, who verified the moons' orbital paths. Of the 12 newly surveyed moons, 11 have orbits that fall neatly in line with previously discovered satellites. Two of those are part of Jupiter's group of inner prograde moons, meaning that they orbit in the same direction as the planet rotates. Nine others orbit with Jupiter's outer retrograde moons in the opposite direction.

The twelfth moon, however, is peculiar.

"Our other discovery is a real oddball and has an orbit like no other known Jovian moon," said Scott Sheppard, lead scientist on the project and a staff scientist at the Department of Terrestrial Magnetism of the Carnegie Institution for Science in Washington, D. C.

This twelfth moon has a wide, 1.5-Earth-year orbit around Jupiter and travels among the retrograde moons. What makes it odd, however, is its maverick orbit: It is the only prograde Jovian satellite discovered to date to orbit at about the same distance from Jupiter as the retrograde moons. The moon, tentatively named Valetudo, also has a more inclined orbit than other prograde moons and is one of the smallest moons of Jupiter discovered to date, measuring less than 1 kilometer in diameter.

The moon "is a real oddball and has an orbit like no other known Jovian moon."

The researchers first observed the new moons in 2017 with the 4-meter Blanco telescope at Cerro Tololo Inter-American Observatory in Chile. They then used telescopes in Chile, Arizona, and Hawaii to confirm the existence of the moons and their orbits around Jupiter, a process that required many follow-up observations over the past year.

Serendipitous Observations and Treacherous Orbits

The astronomers were not intentionally searching for new Jovian moons when they began observing. They had set their sights on the outer solar system and were looking for more evidence of the elusive Planet Nine, a predicted but as yet unobserved large outer solar system planet.

"Jupiter just happened to be in the sky near the search fields where we were looking for extremely distant solar system objects," Sheppard explained. "We were serendipitously able to look for new moons around Jupiter while at the same time looking for planets at the fringes of our solar system."

The two new regular prograde moons join 15 other previously discovered prograde satellites that typically orbit Jupiter in about an Earth year or less. These moons include the famous Galileans: Io, Europa, Ganymede, and Callisto. They also include a cluster of moons beyond Callisto, shown in blue in the image to the left. The seven new retrograde moons join 45 other satellites that take 2–3 Earth years to orbit. The orbits of nine other small Jovian moons are yet unknown.

Astronomers suspect that the retrograde moons may be the remains of larger moons that were destroyed in head-on collisions with prograde objects. Valetudo might be a shattered remnant of one such prograde collider.

Because the new moons are a few kilometers in size, the team thinks that the impacts that created the satellites likely took place after the era of planet formation ended. If the collisions had happened earlier, the moons would likely have interacted with dust and gas leftover from forming Jupiter and been dragged into the planet.

Also, if the moons had formed earlier, there likely would have been more crashes, the team explained. "This is an unstable situation," said Sheppard. "Head-on collisions would quickly break apart and grind the objects down to dust." Given the moons' stable orbits and kilometer-scale sizes, the collisions were likely chance events later in the solar system's history.

Studying these objects in depth will help astronomers learn about the evolution of the early solar system and the complex Jovian system. That's why it helps to find objects that don't quite blend in, the researchers note—the "oddballs" are what end up painting the fullest picture.

By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer

Raising a Tantrum About Climate Change

An illustration from the children's book The Tantrum That Saved the World *by Megan Herbert and Michael Mann. Credit: © Megan Herbert*

Last year, President Donald Trump gave a speech outlining his plans to withdraw the United States from the landmark Paris climate accord, a pact that seeks to limit greenhouse gas emissions worldwide. The move drew heavy criticism from the leaders of other nations, scientific societies, and scientists.

In The Tantrum That Saved the World*, a polar bear is the first character to arrive at the protagonist's door to ask for help. Credit: © Megan Herbert*

One of the harshest critics of Trump's decision has been Michael Mann, a professor of atmospheric science at Pennsylvania State University in University Park and director of the university's Earth System Science Center.

After Trump's speech, Mann tweeted, "Trump's actions are bad for jobs, bad for U.S. global competitiveness, and bad for the planet." Yet Mann remains determined and optimistic that the world can stave off catastrophic climate change. So we asked him how much of a setback Trump's decision has caused in dealing with climate change.

"We'll Still Probably Meet Our Obligations"

The "optics" of the United States withdrawing from the accord "are so awful," Mann told *Eos*. However, he said that despite Trump's declaration, enough progress is being made at local and state government levels and by businesses and others for the country to meet its commitment under the Paris accord.

"No matter what Trump does, in other words, we'll still probably meet our obligations. Now, here's the problem: Paris alone doesn't get us to where we need to go" in terms of reducing greenhouse gas emissions and dealing with climate change, Mann told *Eos*. "We've got to see substantial ratcheting up of those commitments at the next major international conference. And without leadership from the U.S., it's hard to see how we do that."

> "No matter what Trump does…we'll still probably meet our obligations. Now, here's the problem: Paris alone doesn't get us to where we need to go."

Trump's anticlimate policies are "definitely a monkey wrench thrown into the works at a time when everything had to line up if we were going to ramp our emissions down enough to avoid catastrophic warming," he said. "In essence, it means we are going to have to work even harder."

Finding a Broader Audience

One way that Mann has been working hard is through his efforts to communicate the problems and solutions about climate change to the general public. The winner of AGU's 2018 Climate Communication Prize, Mann is the coauthor of an illustrated children's book, *The Tantrum That Saved the World*. He and his coauthor and illustrator, Megan Herbert, first published the book in December 2017.

The book, in language evocative of Dr. Seuss and his Lorax, tells the simple and charmingly written and illustrated story of a girl, Sophia, who gradually becomes aware of the dangers of climate change. She takes urgent action—her tantrum to save the world—after a polar bear, a family from Kiribati, farmers from Syria, New England fishermen, a Bengal tiger,

and others arrive at her door asking for her assistance.

The book begins simply enough:

Sophia was minding her business one day,
When, quite without warning, a bear came to stay.
The ice that he lived on had ceased to exist.
He hoped that Sophia would kindly assist.

After the bear and the others call for her assistance and after Sophia gets stonewalled at a government office, she carries a big "Action Now" banner and energizes people to make a positive change:

Sophia's strong feelings smouldered once more,
And this time they'd gotten too big to ignore.
Raging with purpose, her banners unfurled,
She kicked off a tantrum to save the whole world!

After the story is told, the book continues with a section explaining, in simple terms, global warming and climate change, the plight of the people and animals who arrive at Sophia's door, and the interconnectedness of all of their individual stories. That section is Mann's primary contribution to the book. Herbert played the central role in telling the story and drawing the illustrations, with a lot of interaction between the two coauthors.

"I'm always looking for a new challenge and a new way to communicate the science of climate change and its implications and new audiences to communicate to," Mann said, explaining why he got involved with a children's book.

Characters from The Tantrum That Saved the World *represent some of the people and creatures affected by climate change. Credit: © Megan Herbert*

"I can really think of no [more] important an audience than the youth of this world and their parents. To me, ultimately, that's what it's about: It's what sort of planet we are going to leave behind for our children and grandchildren," said Mann. He also is the author of several other books and coauthor with Pulitzer Prize–winning editorial cartoonist Tom Toles of *The Madhouse Effect: How Climate Change Denial Is Threatening Our Planet, Destroying Our Politics, and Driving Us Crazy*, which was released in paperback in June with a new chapter entitled "The Return to the Mad House: Climate Denial in the Age of Trump."

Mann's Climate Change Elevator Speech to Trump

Mann, who told *Eos* that he doesn't shy away from confronting the climate change "denial machine" and "industry-funded attack dogs," said that if he ever had the chance to give "an elevator speech" to Trump, he would first talk about the president's grandchildren. Then he would talk to Trump about what the national security community calls the threat multiplier of climate change. And noting how America's scientists and engineers have helped the country achieve significant progress and prosperity, Mann said that he would ask Trump, "How can you now turn your back on science and the scientific community simply because you don't find their conclusions politically expedient?"

"My sense is that Trump is probably not intrinsically a climate change denier," he told *Eos*.

"I think that is the position [Trump] has had to reach to pacify the donor class in the Republican Party, the Koch brothers, and the polluting interests," he said. "I think I could probably get him to make some significant concessions in that elevator. The problem would be, once he got out of the elevator and he was back with his handlers, any progress that I had made in that 30 seconds or 2 minutes would probably evaporate pretty rapidly."

Sophia, the protagonist in The Tantrum That Saved the World, *calls the president to talk about climate change. Credit: © Megan Hebert*

Voting Out Special Interests

"My sense is that we can withstand one term of a President Trump/Republican Congress. We can't withstand two terms of that," Mann told *Eos*. He said that there is "enough bureaucracy within the agencies and in the policy process itself," including the lengthy period required for withdrawing from the Paris agreement, to "weather one term" of Trump.

To deal with climate change, what's needed in addition to putting a price on carbon and transitioning more rapidly from fossil fuels to renewable energy is for people to vote, Mann said. "If people don't show up at the voting booth, then we are going to get politicians who represent the special interests, the fossil fuel industry, rather than the interests of the people that they are supposed to represent."

That sounds like something that Sophia, the protagonist in the children's book, might throw a tantrum about.

By **Randy Showstack** (@RandyShowstack), Staff Writer

Geology in 3-D and the Evolving Future of Earth Science

Geologic Mapping Forum
Minneapolis, Minnesota, 26–29 March 2018

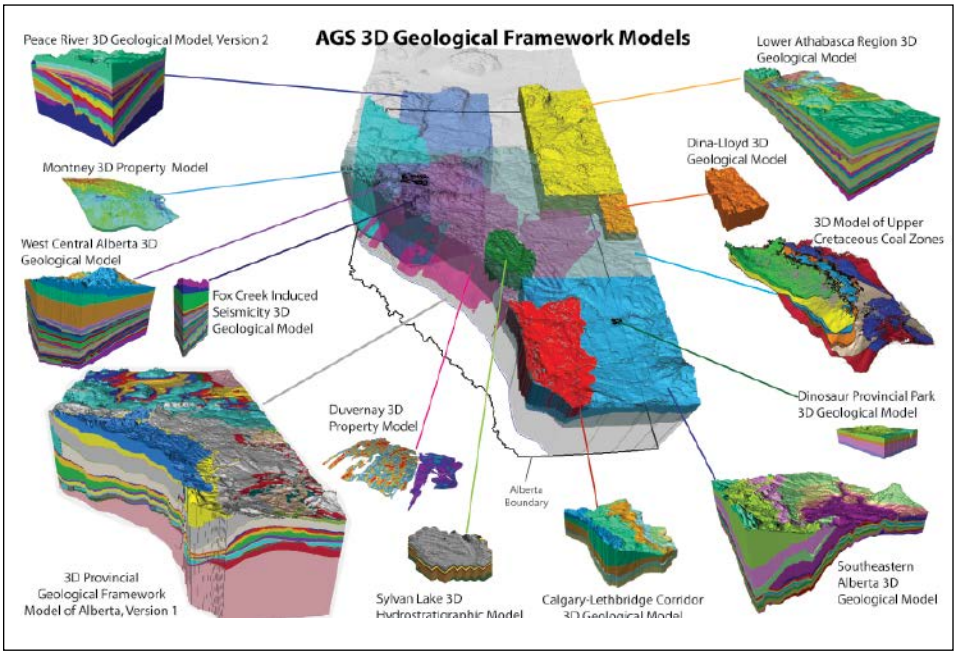


Fig. 1. A spatial breakdown of 12 models that can be used to understand the structures that underlie Alberta. The models, developed at a variety of scales, are helping researchers to understand geospatial relationships and interactions between the surface and the subsurface. Credit: Alberta Geological Survey

Last March, nearly 100 geoscientists from state, federal, academic, and private sector institutions in the United States and Canada gathered on the University of Minnesota campus. They presented current research on and discussed issues related to the latest developments in geologic mapping. They also discussed the synthesis of geological and geophysical information into 3-D models of the North American continent on scales varying from urban to continental.

The geoscientists were concerned with mapping capabilities, from surficial materials to Precambrian basement, from young tectonic environments to well-established cratons, from water and mineral resources to natural hazards to basic science and education.

In his opening plenary, Harvey Thorleifson of the University of Minnesota and the Minnesota Geological Survey briefly reviewed the history of 2-D geologic mapping, from paper maps to Internet-accessible databases. He summarized scientific literature that highlighted enhanced data collection through digital capture of field data and the application of geoinformatics and 3-D methods to create maps.

These advances have enabled the creation of models that contribute greatly to the science and planning of energy, minerals, water, hazards, and infrastructure design. These models are made possible by improved 3-D mapping that is well coordinated with spatial data infrastructure and well supported by global initiatives. Thorleifson suggested that geologic mapping is an essential service, part of a spectrum of activities that benefit society—from research and monitoring to modeling and resource management.

Other presenters gave examples of the process to develop 3-D geological maps on various scales and the applications and benefits of this mapping:

- Kelsey MacCormack of the Alberta Geological Survey presented work on a 3-D geologic model of Alberta that is part of an effort to create a single source of geological information for the benefit of its diverse stakeholder groups (Figure 1).
- Don Sweetkind of the U.S. Geological Survey presented examples of regional groundwater systems, which require a regionally integrated 3-D geologic framework.
- Dick Berg of the Illinois State Geological Survey presented work on 3-D geologic mapping for urban areas, emphasizing the need to protect our local food and water supplies and help inform subsurface infrastructure.

Geologic mapping is an essential service, part of a spectrum of activities that benefit society—from research and monitoring to modeling and resource management.

Attendees recognized the benefits of 3-D geologic mapping and the role that our interconnected electronic world can play to realize and maximize these benefits. They agreed that developing 3-D geologic products that are relevant, accessible, consistent, and readily updatable requires strong coordination among state, federal, academic, and industry partners, as well as a deep appreciation of the needs of potential users.

Attendees were invigorated by the workshop and felt that the Geologic Mapping Forum should continue every 1–2 years and complement the annual Digital Mapping Techniques workshops held each year in late spring (see http://bit.ly/DMT-workshop). A full workshop summary is available at http://bit.ly/3-D-geology.

This meeting was hosted by the Minnesota Geological Survey.

By **O. S. Boyd** (email: olboyd@usgs.gov), U.S. Geological Survey, Golden, Colo.; and **L. H. Thorleifson,** Minnesota Geological Survey, Minneapolis

Human Activities Create Corridors of Change in Aquatic Zones

Human influences, like this road running over a reservoir covered with reeds and duckweed, are driving changes in aquatic ecosystems. The results may be hard to predict. Credit: iStock.com/AlexKazachok2

Humans have been disturbing Earth's landscape ever since we began constructing simple dwelling structures in the Paleolithic (400,000–500,000 years ago). The pace accelerated with the invention of the wheel in the middle Holocene (5,000–7,000 years ago), which enabled humans to travel farther and faster.

But humans haven't been changing land only since antiquity. With the construction of the first man-made canal prior to the Iron Age some 3,600 years ago, we started to control the flow of water for agricultural practices and began perturbing Earth's hydrologic system [*Bishop et al.,* 2017]. This "replumbing" of Earth's surface, recently referred to as anthroturbation [*Zalasiewicz et al.,* 2014], rapidly expanded during the Industrial Revolution (beginning in about 1800 CE) and the "Great Acceleration" (about 1950 CE). This pattern of hydrological landscape modification—or replumbing—continues to this day.

Humanity's replumbing of Earth goes hand in hand with the recent concept of the Anthropocene [*Crutzen and Stoermer,* 2000]. In fact, we posit that new boundaries with steep gradients in aquatic systems, created in the Anthropocene, are providing corridors for rapid organismal and biogeochemical change that warrant examination from a new perspective.

Thus, further understanding the Anthropocene must involve answering some key questions: How has this manipulation of the surface of our planet affected nutrient levels, species diversity, and evolution itself in aquatic ecosystems, and how will these changes continue into the future as climate changes?

To help answer these questions, we propose three specific ways forward.

1. Formally Designate Aquatic Critical Zones as a Focus of Study

Much of the foundational thinking on changing landscapes in the Anthropocene is focused on terrestrial systems. This terrestrial focus is, in part, an outgrowth of one synoptic goal of the National Science Foundation's critical zone observatories program, which was chartered "to develop terrestrial observatories that could document and form predictions of the multi-scale and less visible transport of energy and material, and evolution of the Earth's critical zone" [*Chorover et al.,* 2011].

A critical zone is a "heterogeneous, near-surface environment in which complex interactions involving rock, soil, water, air, and living organisms regulate the natural habitat and determine the availability of life-sustaining resources" [*National Research Council,* 2001]. Although the general concept of critical zones has included aquatic systems, we propose that these areas are dynamic and vulnerable corridors of change, worthy of their own designation as aquatic critical zones (ACZs).

What would need to be done to fully recognize the importance of ACZs and understand their response to change? As a starting point, we see two domains for work:

- Natural ACZs have always existed, but the anthropogenic replumbing of ACZs has resulted in alterations of their spatiotemporal patterns. Landscape responses to these alterations, linked with molecular and organismal mechanisms, need greater consideration in global biogeochemical models.

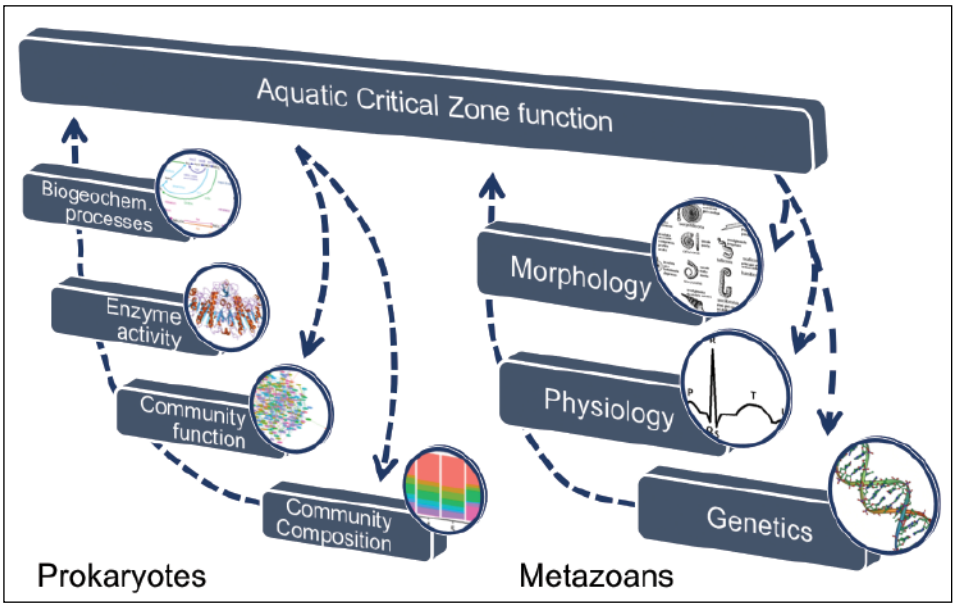


Fig. 2. Organismal and biogeochemical processes are interrelated with functions in the ACZ. Prokaryotes are single-celled microorganisms, and metazoans are the multicelled organisms that compose the animal kingdom.

• The impacts of anthropogenic and climate effects on ecosystems, on scales from genes to landscapes, have been recognized recently [*Bishop et al.,* 2017; *Scheffers et al.,* 2016]. However, these scales must be integrated; genetic change must be considered in conjunction with biogeochemical cycles and ecosystem fluxes, particularly in systems as vulnerable as ACZs.

Although we focus here on the adaptive biogeochemical and organismal ramifications of global change on ACZs, it is important also to recognize potential hydrologic, geomorphic, and ecosystem services that could be linked to define ACZs as a critical research area.

2. Develop a Human Footprint Index for Aquatic Critical Zones

In recent decades, alterations in the transition zone between terrestrial ecosystems and the open ocean, termed the land-ocean continuum, have produced numerous effects in the ACZs. These include hypoxic zones, eutrophication, and altered sediment transport (Figure 1).

Climate change has already affected 81% of ecological processes in marine systems and 74% of these processes in aquatic systems [*Scheffers et al.,* 2016]. In the future, these effects will likely have complex interactions with climate change, which could result in climate feedbacks, ecosystem regime shifts, and potentially catastrophic impacts on the human systems that depend on ACZs.

Engineering projects have addressed issues at the human-aquatic interface, although often with unintended effects. For example, about 87% of Earth's land surface is connected to the ocean by rivers. The approximately 16 million dams now in existence [*Lehner et al.,* 2011] affect these connections between rivers and oceans; dams have altered biogeochemical processes, enhanced greenhouse gas production, and reduced sediment delivery to vital deltaic systems [*Bianchi,* 2016; *Giosan et al.,* 2014]. The increased dominance of artificial structures in aquatic systems has been recognized as "ocean sprawl" [*Bishop et al.,* 2017].

The increased dominance of artificial structures in aquatic systems has been recognized as "ocean sprawl."

Recent work in terrestrial systems quantified anthropogenic effects on mammalian movement with a human footprint index (HFI) that included as key components predator-prey interactions, nutrient cycling, and disease transmission [*Tucker et al.,* 2018]. The development of an equivalent index for aquatic systems would be valuable to quantifying and assessing anthropogenic impacts to ACZs.

Such an HFI could include changes in nutrients, suspended particulates, and water residence times as key components. Analogues to the terrestrial HFI described above, including predator-prey interactions and pollution and disease transmission, could also be included.

Greater cross-disciplinary research that links specific anthropogenic disturbances in ACZs with organismal and biogeochemical changes (Figure 2) would facilitate greater communication between evolutionary geneticists, environmental microbiologists, geochemists, and ecosystem scientists.

3. Study the Genetic Effects of Manipulating ACZs

Vicariance biogeography is a field that looks at the ways in which organism populations become separated and species diverge. At its inception, studies in this field described how large-scale geographic barriers (e.g., mountain ranges and rivers) affected the geographic spread of genetic characteristics [*Wiley,* 1988].

Anthropogenic manipulation of ACZs results in the formation of new barriers and corridors [*Bishop et al.,* 2017] in Earth's plumbing. At times, these modifications can reach the scale of natural geomorphic features associated with the vicariance biogeography of multicelled animals.

Physical barriers or corridors from anthropogenic disturbance directly affect the movements of living organisms, but indirect effects, such as alterations in nutrient availability, have also been observed. For example, recent research suggests that large-scale disturbance from such artificial structures as levees and dams in ACZs may have the capacity to affect the drivers of evolutionary change in multicellular organisms, as in the case of altered migration patterns of marine mammals [*Bishop et al.,* 2017]. Drivers of such change include mutation, migration, genetic drift, and selective pressures. What's more, these drivers could produce dynamic and complex interactions with a changing climate.

In addition to altering the evolutionary trajectories of higher organisms, anthropogenic disturbance in ACZs is also likely to influence microbial community structure and function. Microorganisms, as the engines of Earth's biogeochemical cycles, clearly are at the front lines of response to changing biogeochemical gradients in ACZs. However, microbes will likely respond to anthropogenic change differently than multicellular creatures because of complexities associated with microbial biogeography. Plus, humanity's replumbing of Earth's surface is likely to result in changes in community composition and function.

Environmental factors can influence microbial communities on a landscape scale,

but evaluating their response to global change is challenging. New frameworks are emerging that consider microbial response (e.g., community composition) versus effect (e.g., functional traits) in the context of global change. Linking alterations in community composition and function with ecosystem-scale processes may improve our ability to predict ACZs' response to global change, although some microorganisms may exhibit response traits that may not translate to changes in ecosystem-scale processes.

Earlier studies called for further integration of the geosciences and microbial ecology [*Moran et al.*, 2013], an exhortation that we support and now extend to include an emphasis on ACZs in a changing climate.

We propose that the integration of microbial ecology with chemical biomarker studies will allow for a comprehensive evaluation of biogeochemical cycles and microbially driven processes, providing data and hypotheses necessary for critical insights into the complex interacting processes underlying the global impacts of anthropogenic change in ACZs.

Critical Needs in Aquatic Critical Zones

Numerous studies have evaluated ecosystem responses to climate-driven changes, including alterations in temperature, acidity, salinity, and hydrology. One consistent theme is the susceptibility of ACZs to altered regimes and their potential nonlinear response to climate change.

Recent studies all point to how ACZs are highly susceptible to change and that their response to change not only may alter the composition and function of their resident organisms but also will have disproportionate impacts on neighboring human populations that depend on them. These studies, however, only scratch the surface.

We urgently need more work to investigate how human influences are affecting ACZs to get a full picture of the extent of the Anthropocene and better predict how these systems may respond to change.

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By **Thomas S. Bianchi** (email: tbianchi@ufl.edu) and **Elise Morrison,** Department of Geological Sciences, University of Florida, Gainesville

Tying Knots on a Research Vessel

Jill Karsten and Rodey Batiza at their 13 February 1988 wedding ceremony aboard the R/V Thomas Washington*, en route to the East Pacific Rise. Credit: Ron Comer*

The year was 1988. The R/V *Thomas Washington*, a gem in the Scripps Institution of Oceanography's fleet, sat idle at the dock. Checking his watch, the chief scientist frowned and strode to the bridge to ask why they had not yet departed Acapulco.

"We are waiting for one more delivery," Capt. Tom Desjardins replied with a sly smile. Fifteen minutes later, a blue panel truck pulled onto the dock. A stocky man rolled up the back door to reveal the only cargo and the cause of the delay: a white-frosted, three-tiered cake.

The chief scientist chuckled, incredulous at the sight. The cake, ordered by the ship's cook, was for a shipboard wedding that would take place during the transit—his wedding.

Casting Off

They originally met through an introduction by her adviser, John Delaney, at the AGU Spring Meeting in Philadelphia in 1982. He was a professor at Washington University in St. Louis; she was a graduate student at the University of Washington in Seattle. They both studied mid-ocean ridge processes and seamount volcanism and tectonics—lives spent cruising the balmy, calm seas of the East Pacific Rise (him) and hanging on for dear life in the swells and squalls of the Juan de Fuca Ridge (her).

They met during simpler times: before GPS, when seafloor maps were hand contoured and interpolated and geological intuition was essential to the toolbox; when the most valued technologies brought on a research cruise were well-engineered 10-point dividers, parallel rulers, and a sharpened set of Prismacolor pencils. They both knew the thrill of a rock dredge ascending from the seafloor, the anticipation of glassy, black rocks that might reveal the mantle's secrets, and the fear of a completely empty dredge.

For many years, their paths crossed only at the annual AGU Fall Meeting in San Francisco. Back then, the meeting was small enough to be held at the Jack Tar (later Cathedral Hill) Hotel on Van Ness Avenue and the nearby Holiday Inn Golden Gateway. The community studying mid-ocean ridges was small, so with few competing Volcanology, Geochemistry, and Petrology sessions of interest, everyone in the field could be found in the same room.

True to conference form, they heard about each other's current research in 15-minute synopses, presented using overhead projectors and decks of 35-millimeter slides that occasionally arrived upside down. But she was a graduate student, so they rarely crossed paths during the after hours, when conversations and negotiations about proposals and manuscripts filled the voids around the technical program.

A Change of Course

As her Ph.D. neared completion and she began applying for academic jobs, she asked whether he would write a letter of recommendation on her behalf. He was familiar with her research, through AGU talks and reviews of her *Journal of Geophysical Research* publications; she thought that his stature as a leader in this subfield would lend credence to her application.

Running into her at the next Fall Meeting icebreaker, he suggested they meet. He wanted to know more about her research plans, to better prepare for writing the recommendation.

After the recommendation was filed, they continued to correspond. Over time, conversation diverged into more personal topics and mutual flirtation. It became clear that they were on the brink of charting a new course.

Romance blossomed quickly, despite the distance between Seattle and Northwestern University in Illinois, where he now held a position, and the limitations on communication posed by the pre-email era. Six months after their conversation at Fall Meeting and numerous, expensive phone calls and letters later, they found themselves together on the R/V *Moana Wave*, invited by Daniel Fornari of Woods Hole Oceanographic Institution to map volcanoes near the East Pacific Rise using the new SeaMARC II side-scan sonar imaging system.

The Wager

A month of proximity at sea served as a powerful catalyst for their long-distance relationship. By summer, he had declared his intention to propose.

But there were complications. She had already accepted a job at the University of Rhode Island (URI), to begin in the fall. So he proposed a counteroffer, with plan A and plan B scenarios.

In plan A, she would gracefully withdraw from the URI position and marry him right away. Plan B provided her with a 2-year stint at URI, capitalizing on its offer of start-up funding, but presumed the same marital out-

Karsten and Batiza exchange vows on the R/V Thomas Washington*'s bow in a 1988 ceremony officiated by the ship's caption. Credit: Ron Comer*

come. He felt pretty confident about where things were going to end up!

They solved the dilemma through wagering on different scenarios over a game of pool. He wins? Plan A. She wins? Plan B.

Technically, she lost. Thankfully, her URI colleagues were extremely understanding. There was some cheerful ribbing about the possibility of mobsters from Rhode Island showing up at his door one day in retaliation, however!

Fortunately, her career setback was short-lived. That October, after defending her dissertation, she moved to Evanston and earned an assistant research professorship at Northwestern University.

A Special Union Session

He formally proposed, on bended knee, to the delight of her family. Her mother and her sister Tracey, who lived near San Francisco, were eager to celebrate the engagement.

Knowing that most of their friends were also colleagues who lived across the country and abroad, AGU Fall Meeting offered the perfect venue. They coconvened a "special session" focused on "Union business" with a reception at the Little City Antipasti Bar, a small Italian restaurant in North Beach. The evening of good wine, friendship, and tall tales from past cruises provided a delightful christening ceremony for their lives together.

As luck would have it, he was scheduled to lead another research cruise 2 months later. Having sailed with "Captain Tom" many times before, he felt comfortable posing the question: Can you marry us during the cruise?

"I'm afraid that's not possible," Capt. Tom said. "You can only do that if you are licensed as a justice of the peace. The captains on the big cruise liners can do that, but not me."

"But," he added spritely, "we can put on one heck of a ceremony, and even better, I can grant you a divorce at the end of the leg!"

Anchored Together

And so the big event was planned for the third day at sea, in transit to the East Pacific Rise. On a glorious, sunny day, they stood on the bow of the R/V *Thomas Washington*, she in a pretty lace dress and he in a tie and sports coat. They both wore flip-flops. She carried a bouquet of yellow chrysanthemums still fresh from Acapulco.

Capt. Tom read passages from Kahlil Gibran's *The Prophet*. Members of the scientific crew—with John Brodholt (University College London) and David Vanko (Towson University) fronting the band—performed a set of ribald songs that they had crafted together the night before. Most memorable was their rendition of "Dredging Woman," sung to the tune of "Honky Tonk Women."

The weekly Saturday "barbecue on the fantail" dinner doubled as the wedding reception. The now infamous three-tiered wedding cake—hastily repaired after suffering a blow in the refrigerator from a falling ham during transit—served as the centerpiece. Four hours later, the bridge called the main lab to announce that they had arrived at the first dredge station.

Newlywed Batiza kneels next to his wedding cake, which had survived a small smashup on its transit to the East Pacific Rise. Behind him are ocean bottom seismometer recorders. Credit: Ron Comer

For the next 30 days, the chief scientist, his new wife, and the rest of the crew mapped and dredged around the clock. The couple like to joke that they went on a cruise for their honeymoon!

New Voyages Charted

In June, a more formal and legally binding wedding was held at the Northwestern University chapel. Their honeymoon in Maui was briefly interrupted by a side trip to Oahu for her to have a job interview at the University of Hawai'i at Mānoa (UH Manoa).

Six months later, they both joined the faculty at UH Manoa, he as a full professor in the Department of Geology and Geophysics, she as an assistant researcher in the Hawai'i Institute of Geophysics. They stayed in paradise for 12 years before returning to the mainland to explore other career opportunities. Eventually, they both ended up working as longtime program directors at the National Science Foundation.

This year, Rodey Batiza and Jill Karsten celebrated their two thirtieth anniversaries: the 13 February 1988 R/V *Thomas Washington* ceremony and the formal 10 June wedding. A blended family, they have three grown sons (Eric, Rodey, and Travis), with the youngest being theirs.

They relocated recently to Minnesota, putting them closer to the boys and their two young grandsons. Minnesota is about as far away as one can get from the ocean, but they remind themselves that it's a problem easily cured by paying a little airfare, especially during the brutal winter months of the upper Midwest. And, after all, being close to family was always one of the most important things they had in common.

They're retired now, but they still attend AGU Fall Meeting. AGU has been at the nexus of much of their professional and personal story, a touchstone throughout their intertwined careers and lives of adventure.

Fall Meeting offers a familiar place to see old friends and catch up with former colleagues, to hear about new science, and to reminisce about days long ago, before GPS and email, when Union business and shipboard weddings were all the rage.

By **Jill Karsten** (email: jkarsten55@gmail.com), Duck Lake Enterprises, Eden Prairie, Minn.; and **Rodey Batiza,** Department of Earth Sciences, University of Minnesota, Minneapolis

Sunlight passing through a colander makes crescent moon shapes on a woman watching the 21 August 2017 solar eclipse. Credit: Tegra Stone Nuess/DigitalVision/ Getty Images. (Facing page) The Moon's shadow covers the Sun during the eclipse. Credit: Jorge Villalba/E+/ Getty Images

GREAT AMERICAN ECLIPSE DATA MAY FINE-TUNE WEATHER FORECASTS

By Temple R. Lee, Michael Buban, Michael A. Palecki, Ronald D. Leeper, Howard J. Diamond, Edward Dumas, Tilden P. Meyers, and C. Bruce Baker

On 21 August 2017, the skies across the United States darkened as the Moon passed in front of the Sun. This celestial event, dubbed the Great American Eclipse, was the first total solar eclipse since 1918 to traverse the full width of the continental United States.

As millions of onlookers witnessed the extraordinary midday darkness and stillness brought on by the Moon's shadow, a national meteorological observing network was doing what it always does. Every 5 minutes the U.S. Climate Reference Network (USCRN) was taking accurate and precise readings of surface temperature, air temperature, humidity, and other environmental conditions at 114 automated stations across all 50 U.S. states [*Diamond et al.,* 2013].

Although taking those readings was just routine work for the network, our team foresaw that the coincidence of USCRN's ordinary data gathering with this remarkable eclipse could yield something extremely useful. That's because many phenomena, from the daily setting of the Sun to such fleeting events as dust storms and passing clouds, suddenly disconnect some piece of the land–atmosphere system from its main energy source, the Sun.

Many computer models developed to simulate and predict the land–atmosphere system's behavior—in particular, weather forecasting and climate models—have difficulty accurately reproducing the system's response to such disconnections and reconnections when they occur quickly or locally. In other words, problems arise when simulating such events on a scale

of a few minutes to a few hours or when they occur in only small patches of a wider region.

Although eclipses might seem unrelated to weather and too rare to have implications for weather forecasting, they have the same effect of rapidly reducing the amount of incoming sunlight as other passing events that occur frequently and do affect the weather. Using data about the Great American Eclipse's meteorological effects allows us to identify deficiencies in weather forecasting models and make improvements to them. These improvements help lead to better weather forecasts.

Data from the Great American Eclipse allow us to identify deficiencies in weather forecasting models and make improvements to them.

Coast-to-Coast Laboratory

For us, the Great American Eclipse was a grand, controlled experiment in a laboratory the size of a continent. Much like the results from any controlled laboratory experiment, USCRN's measurements during the eclipse, from stations equipped with uniform suites of instruments, captured a telling set of responses to one type of change to the system. The eclipse applied that change across a wide range of geographic regions, climate types, and percentages of totality.

Across the entire USCRN, complete obscuration, or darkness, occurred at nine stations during the eclipse. Totality among those stations ranged from 0.52 minute at Lincoln, Neb., to 2.55 minutes at Crossville, Tenn. Fifty-four more stations had at least 75% obscuration, and all but one had at least 50% (Figure 1).

To gather the measurements relevant to the Great American Eclipse from USCRN's database (all free and publicly available), we extracted the data collected every 5 minutes by each station from 2 hours before the moment at which the greatest obscuration of the Sun's disk took place at that location until 2 hours after that moment. We then calculated the changes in select meteorological variables, for example, air temperature, surface temperature, and relative humidity, during that period.

This unique data set is now helping meteorologists, climatologists, and environmental scientists to better understand and characterize feedbacks between the surface of the land and the overlying atmosphere during brief and/or localized interruptions in solar radiation. Those interruptions include a broad range of events such as when dense fog blankets an area, a dust storm arrives, prolonged wildfires break out, or a volcano's ash cloud temporarily obscures the Sun.

Likewise, efforts to use the data to improve models of the land–atmosphere system are under way. For instance, some of our colleagues at National Oceanic and Atmospheric Administration (NOAA) laboratories in Boulder, Colo., are using our eclipse data to help evaluate high-resolution weather forecasting models, such as one called the High-Resolution Rapid Refresh (HRRR) model. A next-generation weather forecast model, HRRR

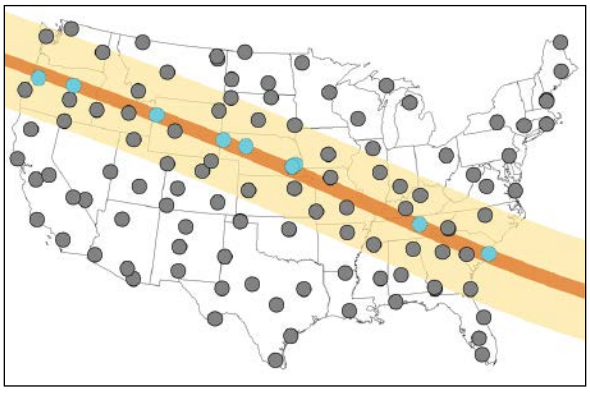

Fig. 1. USCRN stations across the United States. Blue circles represent stations in the path of the 21 August 2017 total solar eclipse. In southeastern Nebraska are two stations near each other.

assimilates radar data every 15 minutes and generates an updated forecast every hour. In contrast, the Global Forecast System and other more traditional weather forecast models, used widely in the United States by the National Weather Service, military branches, TV meteorologists, and others, typically produce new forecasts every 6 hours.

Wide-Ranging Responses

What effects did this grand experiment actually reveal from the eclipse's switching off and on of local sunlight? The findings themselves are unremarkable in that the observed effects, such as the air and surface temperature decreases (Figures 2a and 2b) and relative humidity increases (Figure 3) as the Moon darkened the Sun's disk, were well known and expected. Rather, capturing at multiple and varied locations precisely how much change took place and at what rates is the key result.

As expected, the largest impacts from the eclipse were found along its centerline. Other factors such as cloudiness and vegetation cover also affected land–atmosphere responses. Fortunately for this attempt to gauge exactly the impacts of solar obscuration, the Moon blocked the Sun at a time of day when solar radiation was strong and most of the United States had little cloud cover.

The effects were also stronger in the eastern part of the country, where daytime heating had progressed further and air masses had higher moisture content than in western states.

Overall, maximum cooling at USCRN stations ranged from 2°C to 5°C near the centerline (Figure 2a). Surface temperatures fell at 109 sites, with decreases ranging from 5°C to 15°C (Figure 2b). These often undergo greater variations than air temperatures because the ground does a better job radiating heat than the air.

To illustrate the changes in solar radiation and temperature and the rapid pace at which those variations occurred because of the eclipse, our team created an animated map. The map uses colors to depict solar radiation intensity and temperature differences recorded by USCRN stations every 5 minutes during the Great American Eclipse. You can watch it at http://tinyurl.com/USCRN-eclipse. (To start or stop the animation, click on the Time Slider icon at the top left.)

In addition, available online for free download from an FTP site (http://bit.ly/FTP-1) is the full set of 5-minute data from the eclipse. You can also download animations of eclipse-related changes to solar radiation, air and surface temperatures, and relative humidity from our laboratory's website (http://bit.ly/map-etc).

A Different Perspective

To independently validate the findings from the USCRN experiment, our team also monitored the eclipse with another set of instruments deployed near the town of Ten Mile, Tenn., which lies 75 kilometers southwest of Knoxville and was in the path of totality. This site was ideal because it was in totality for 2.63 minutes, and fair weather conditions allowed for eclipse effects to be maximized.

There, NOAA scientists from the Air Resources Laboratory (ARL) Atmospheric Turbulence and Diffusion Division (ATDD) in Oak Ridge, Tenn., installed instru-

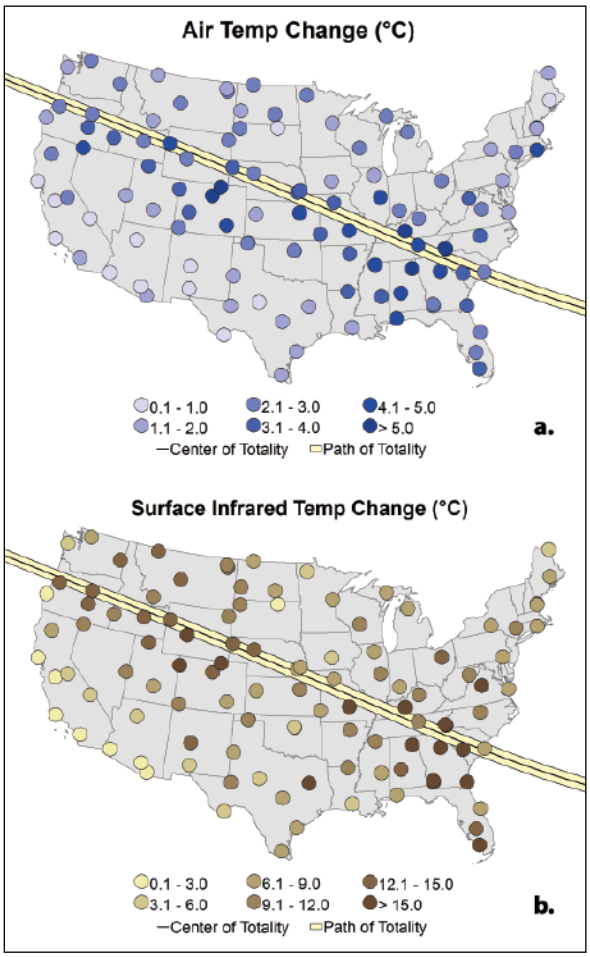

Fig. 2. Decreases in (a) air temperature and (b) surface infrared temperature between the maximum temperature within the 2 hours prior to the closest approach to totality and the minimum temperature during the eclipse event at USCRN stations in the conterminous United States.

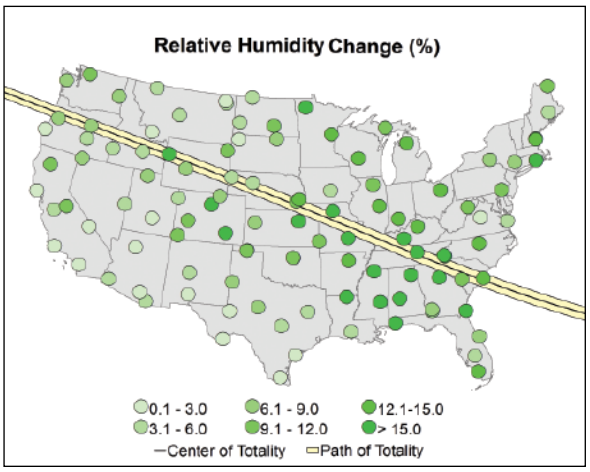

Fig. 3. Increases in relative humidity between the minimum relative humidity within the 2 hours prior to closest approach to totality and the maximum relative humidity during the eclipse event at USCRN stations in the conterminous United States.

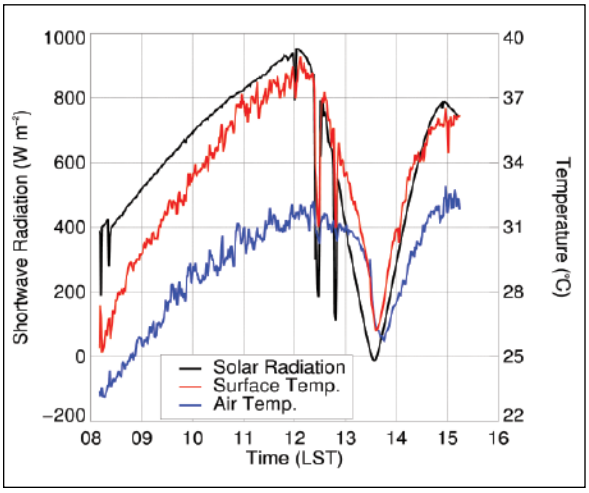

Fig. 4. We found that consistent with the USCRN sites in the path of totality, temperatures at Ten Mile, Tenn., during the day of 21 August 2017 rapidly decreased during and shortly after eclipse totality. Surface temperatures (red) decreased by nearly 12°C, and the air temperature (blue) decreased by 5°C. Following these temperature minima, both surface and air temperatures returned to near preeclipse values. The black line depicts incoming solar radiation (in watts per square meter) at the site. Times are in local standard time (LST).

ments, including some mounted on a drone. These instruments measured temperatures of the ground surface and air (both also measured at all USCRN sites) as well as incoming and outgoing shortwave radiation (from the Sun) and longwave radiation (from Earth). Horizontal and vertical winds were also measured to study land–atmosphere interactions during the eclipse. Changes in all of the above meteorological conditions at Ten Mile proved consistent with findings from USCRN (see Figure 4 for Ten Mile temperature and solar radiation data).

Other measurements provided additional insights into the rapid changes in near-surface energy during the eclipse. Sensible heat flux, or transfer of heat from Earth's surface into the atmosphere, decreased to near 0 watts per square meter around totality but increased toward the end of the partial phase.

We also found similar patterns in turbulent kinetic energy, or how much the air motion varies, during the eclipse. These large-scale, eclipse-driven patterns suggest that small-scale changes that happen whenever the surface energy is rapidly removed—for instance, by thick clouds or heavy aerosol loads obscuring the Sun—might likewise decrease the amount of turbulence in the lower atmosphere. This decrease could lead to less energy exchanged between the surface and the atmosphere, which would further reduce the turbulence.

A Complementary Study

Whereas the continental-scale data set we gathered from USCRN offers us one way to study feedbacks between the land surface and the atmosphere, targeted regional field studies provide another.

For example, several authors of this eclipse study are involved with the Land–Atmosphere Feedback Experiment (LAFE) [*Wulfmeyer et al.*, 2018], a monthlong endeavor in northern Oklahoma in August 2017 that used a dense network of sophisticated, near-surface meteorological observations to seek ways of better representing very complex interactions between the land surface and the atmosphere. Although the eclipse was not the focus of LAFE, the site did experience 89% obscuration, thereby providing another rich data set on the rapid, near-surface changes that occurred during the Great American Eclipse [*Turner et al.*, 2018].

By combining such observations from fieldwork on relatively small scales with continental-scale observations like those from USCRN, we expect to gain new perspectives on the interactions and processes occurring within the lowest part of our atmosphere. Increasing our knowledge about these processes and learning how to better represent them ultimately will improve the weather forecasting models on which we all rely for our day-to-day activities.

Acknowledgments

We gratefully acknowledge the hard work of the USCRN technicians from NOAA/ARL/ATDD for installing and maintaining the network. We thank Mark Heuer from NOAA/ARL/ATDD for assembling the instruments used on the tower at Ten Mile and Kym, Tom, and Jerry Swanks, who allowed us to install the tower. We thank Devin Thomas of ERT Inc. at NOAA National Centers for Environmental Information for assistance with graphics. We thank Michael Potter and Rick Saylor from NOAA/ARL/ATDD for developing the eclipse web pages. We acknowledge Rick Saylor and an anonymous reviewer, whose suggestions helped improve the quality of this article. Finally, we note that the results and conclusions, as well as any views expressed herein, are those of the authors and do not necessarily reflect those of NOAA or the Department of Commerce.

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DIGGING DEEP INTO GEOSCIENCES WITH MINECRAFT

By Laura Hobbs, Carly Stevens, and Jackie Hartley

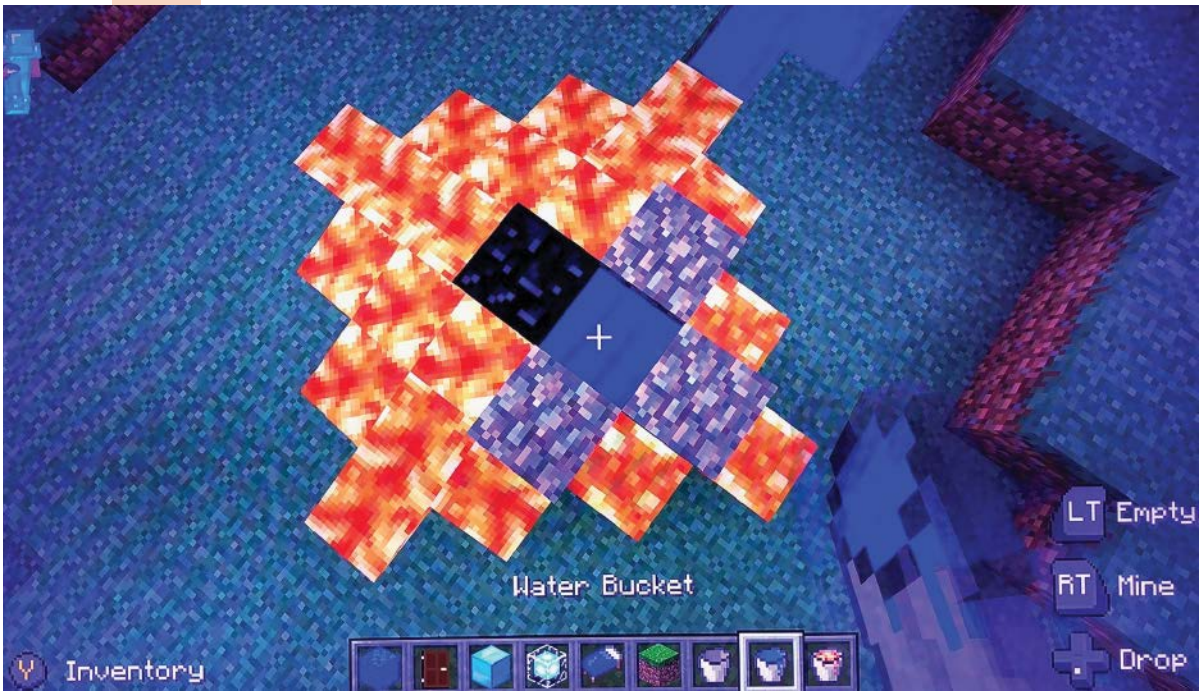
Photo: iStock.com/vgajic; Laptop image: Minecraft/Mojang, build by Beth Bagley; Design: Travis Frazier

Imagine yourself in a world where everything is made up of cubes. Colorful blocks represent rocks, trees, water, and animals. An erupting volcano produces blocks of flowing lava. A cave contains cubes of iron and gold ore.

Sound familiar? This is the world of Minecraft, a hugely popular "open-world" construction-based video game in which players can move around freely and build virtual creations by "mining" and placing textured blocks with different properties. You can build elaborate cities and ships—even the Eiffel Tower or Tolkien's Minas Morgul. You can also build a working computer that can perform calculations.

But what if you could build your own Earth features and explore the real-life science behind them?

This is what we do at Science Hunters, an outreach program at Lancaster University in the United Kingdom. In the blocky world of Minecraft, we task players with building dinosaurs, rockets, volcanoes, caves, and even whole planets. From seeds to space, they can explore and relate the processes they interact with in the game to the real world around them.



In Minecraft's creative mode, lava can be cast from a bucket onto the ground. Pour a bucket of water in the vicinity of this lava, and the hottest parts will turn into obsidian, as seen here. Credit: Minecraft/Mojang, build by Mohi Kumar

In workshops run by Science Hunters, children use Minecraft to gain skills in creative thinking, problem solving, teamwork, and communication, all while exploring complex scientific concepts through experiences that are simply not possible in everyday life. How else can you play with molten lava?

Hot Cubes

Each Science Hunters workshop involves a theme, such as volcanoes or oceans. First, away from computers, we introduce the topic with hands-on demonstrations of real-world examples.

For example, in the volcano theme, we show students real examples of obsidian, rhyolite, and pumice. We talk about their formation, along with hazards associated with them and how we might protect ourselves against these. Then we ask the students to enter the Minecraft world in creative mode and start building their own volcano.

Water, lava, and obsidian play a role in advancing objectives in Minecraft's survival mode game play, so many students come to sessions with Minecraft-related knowledge of these block types. For example, water and lava blocks in Minecraft flow downward and spread out—just like they would under Earth's gravity—and vegetation may be set alight by lava. We take that baseline knowledge and help the student go steps farther.

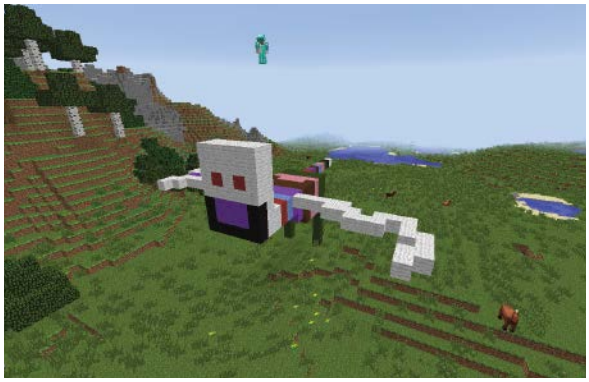
In real life, obsidian—volcanic glass—can form when lava comes in contact with water and cools instantly, so that crystals do not have time to develop. In Minecraft's creative mode, obsidian can form when you take a bucket of lava from your inventory and cast it over the ground. The lava mounds into a tiny hill; the "source" and hottest part of the lava flow, from which the mound is "erupting," is the very first lava block you placed down from your lava bucket. Cast a bucket of water—also found in your inventory—near that source of lava, and if the water hits it, that source block will turn into obsidian. Other blocks in the lava flow, moving outward from this source block, are coded to be not as hot; these blocks will solidify as the water runs over them, but they do not create obsidian. Instead, they turn into blocks that represent crystalline lava rocks.

These behaviors reflect real-world geologic processes, which gives us an opportunity to talk with the children about the differences between crystalline rocks and volcanic glass, crystal sizes and growth rates, subaerial and subaqueous cooling, and properties of dynamic flows and solid rocks. We also talk about the impact of the volcano they build on the ecosystem surrounding it and villages nearby.

We discuss all these things while the students dig, build, and play. Each session revolves around a Minecraft challenge. In the volcano theme, we encourage students to create volcanoes complete with plumbing, eruptions, lava-water interactions, and external structures that need protecting from hazards when they erupt.

The World in Blocks

We use a version of Minecraft specifically designed for educational use, which means that we can ensure that game play functionality is appropriate for the classroom. Operating the game in its creative mode is key: This mode gives players an unlimited number and very wide range of blocks to build with. It also means that players don't have to keep themselves alive in the game, as they would in its survival mode. Another perk is that players can fly around in their virtual world.



A student-designed model of a pterosaur, created in a Science Hunters workshop. Credit: Minecraft/Mojang, build by Science Hunters

This version and mode open a wealth of possibilities to explore science through virtual creation. Think of it like playing Legos, except that you have infinite blocks with dynamic properties in all the colors of the rainbow. Just imagine what you could build!

Through Science Hunters, we invite students to imagine with us. In addition to the class on volcanoes, we run a variety of other sessions, each focused on a different theme: dinosaurs, caves and minerals, rockets, planets, mining, ice and snow, and oceans, to name a few.

For example, we guide children through dinosaur and pterosaur classifications and use scientifically accurate toys as well as templates of real dinosaur footprints to show sizes and scales of dinosaur features. The students then use this information to build a model of a Mesozoic creature, either reconstructing a known example or designing their own.

In a different session, we show children a variety of mineral samples, discuss the differences between stalagmites and stalactites, and then set them to work to dig down and construct their own caves. Going extraterrestrial, we show students models of the structure of the solar system and of individual planets. Then, using a planet-themed Minecraft world and a resource pack that enable a virtual space environment, students can build their own planets from core to crust.

Bricklaying

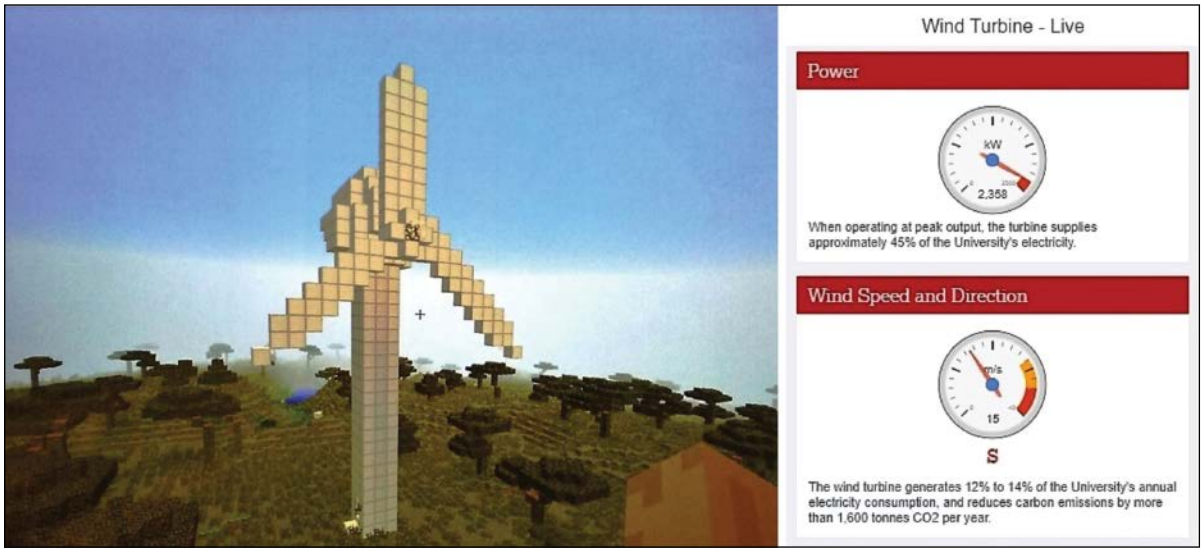
Minecraft can be used as a teaching tool to construct more than just natural features. It can help teach students how the built environment—buildings, agriculture, transportation routes—influences nature.

For example, how are we going to produce enough healthful food in the future, as our population expands and builds on the very farmland we need to produce that extra food? Through one of our classes, children inspect raw, unprocessed real-world samples of foodstuffs represented in Minecraft. Then they design and build their space-saving solutions to this dilemma in the game, making use of the game's crops, which respond to sources of light, water, and fertilizer as they grow.

In other sessions, we give students a tour of Lancaster University's own wind turbine. We examine its energy production through statistics and the turbine's online live data feed to demonstrate generation and use of renewable energy. Then we ask the children to design and build renewable energy production mechanisms. This can be a stand-alone task or an expansion of our exploration of town planning, in which children build their own cities, including power networks, onto grid systems.

Built environment lessons can also envision scenarios off our world. After leading students through a discussion on what they'd need if they were to live on another planet, we turn students loose in a premade barren Minecraft landscape, reminiscent of Mars or the Moon, to design their own space station.

A Minecraft wind turbine, modeled after a real instrument at Lancaster University. This virtual turbine was built at the Science Hunters' regular Minecraft Club, aligned with the current wind direction at the time based on live data from the university's turbine. The real turbine can be seen by all attendees as they travel to and from club sessions. Credit: Minecraft/Mojang, build by Science Hunters



A student-designed snowflake model, built in Minecraft using virtual blocks of snow. Credit: Minecraft/Mojang, build by Science Hunters

Virtual Ecology

Minecraft contains a range of representative ecological biomes, so we created instructional packets containing booklets, posters, and stickers that we sent out across the United Kingdom (with the support of the British Ecological Society) to guide families through ecological explorations on their own time at home. We supply an introduction to biomes and their associated animals, plants, habitats, and foods, all clearly linked to the equivalent features in Minecraft, with building challenges to complete in Minecraft along the way. We also provide a series of experiments and identification activities. For example, we give families seeds to grow cacti and food crops found in Minecraft, along with fertilizer to demonstrate how, just like in the game world, real plants can get a growth boost when fertilizer is added. We also provide some wood samples of tree species present in the game, linked to information about the biomes in which those trees are found.

Our workshops also investigate flora and fauna through Minecraft, delving into how organisms adapt to their environments. We first experiment, outside of the game, with analogies such as insulated versus noninsulated beakers of water to explore heat retention and loss, to which animals adapt through features such as fur coats and large ears. Then we ask students to use these concepts to build an animal that would flourish in the Minecraft biome they are playing in.

Cold biomes are particularly useful as a basis for discussing how snow and ice form, why igloos are not cold inside, and why every snowflake is unique. In our sessions, students can roam around snowy Minecraft plains building igloos and designing their own intricate models of radially symmetric snowflakes.

At other times, we dive into ocean environments, exploring the undersea world and learning about its inhabitants in our own seas before students build their own seascapes. This topic also offers a great opportunity to talk about pollution, plastics, and microplastics in the oceans, and from there students often turn to considering their own environmental impacts.

Geosciences Through Gaming

Science Hunters activities take place in schools, at public events such as community festivals, and at a regular on-campus club offered to local children with autism. We work with children of all ages, with a core audience of around 7–11 years, in several different areas of the United Kingdom. Our team encourages children to play in pairs to support their development of social communication and teamwork skills.

Science Hunters aims to make science learning fun and accessible to everyone. Here a 7-year-old girl examines a slide using a research microscope at a Science Hunters public event. Credit: Steve Pendrill

Sessions and content are highly adaptable to the ages and needs of the children taking part; we may be working with 4-year-olds who have been in school for only a few months, highly able students, or high school students with special educational needs.

We aim to embed the idea that science learning can be fun, engaging, and open to anyone. We also hope to inspire an interest in science beyond the confines of the classroom.

Minecraft is an ideal medium for science outreach and engagement, as it is generally very popular with children. *Lane and Yi* [2017] described it as one of the most widely used and important games of the current generation. Just a mention of the game draws children's attention and interest.

Learning by Playing

Since the program's inception in 2014, feedback collected from all areas of the project has been overwhelmingly positive. Children appreciate the opportunity to explore new topics, participate in hands-on demonstrations, and ask in-depth scientific questions to people with relevant scientific knowledge and expertise. They tell us that using Minecraft makes the session fun and different from their usual lessons and helps them to understand the topics. And when we ask them to tell us something that they've learned, every one of them can do it. We've even heard "This is the best day of my life!"

Parents and teachers often tell us that during Science Hunters sessions, children who often find it difficult to participate in standard lessons are engaged and absorbed in the session. We've seen enthusiastic teamwork from children whom we've been told have a history of interacting poorly with others. Some of these students even high-five their partners at the end of the lesson. In addition, we've found that through using Minecraft, children can both demonstrate what they've learned within the session and, by consolidating their learning through the game, remember it later.

Inspiring the Next Generation

Our use of Minecraft presents a novel and inclusive way of inspiring interest in geosciences in a new generation. The irony here doesn't escape us: The virtual world of Minecraft allows us to bring the real world into the classroom. It allows us to teach students about the outdoors from indoors in a way that wouldn't be possible outside. And our program gives students the tools and support they need to build their understanding of the outdoor real world, block by virtual block.

For more information, access to our program, and ideas about how to structure Minecraft-based geoscience learning for your students, your children, or yourself, visit our website (http://www.lancaster.ac.uk/sciencehunters) or contact us directly.

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EXPLORING THE UNKNOWN

THE ROSS SEA IN SEA ICE–FREE CONDITIONS

By Laura De Santis, Florence Colleoni, Andrea Bergamasco, Michele Rebesco, Daniela Accettella, Vedrana Kovacevic, Jennifer Gales, Kim Sookwan, and Elisabetta Olivo

An international team of scientists boarded the R/V *OGS Explora* in the port of Hobart, Tasmania, on 19 January 2017, heading out on a 2-month expedition to unlock the secrets of Antarctic ice sheet response to past, present, and future climate change.

The team, whose members hailed from Italy, Great Britain, China, Croatia, France, Spain, and South Korea, met the smallest extent of Antarctic sea ice that has been recorded in the past 20 years. This unusual circumstance provided the rare opportunity to circumnavigate the Ross Sea and collect unique data in places that are almost always covered by ice and had remained unexplored.

Funded by the Italian National Antarctic Research Program (PNRA) and the European EUROFLEETS project, the scientists aboard the *OGS Explora* brought expertise in disciplines such as geology, geophysics, oceanography, glaciology, and climatology. The vessel itself, owned by the Italian National Institute of Oceanography and Applied Geophysics (OGS), was on its eleventh Antarctic expedition.

Andy Myatt / Alamy Stock Photo

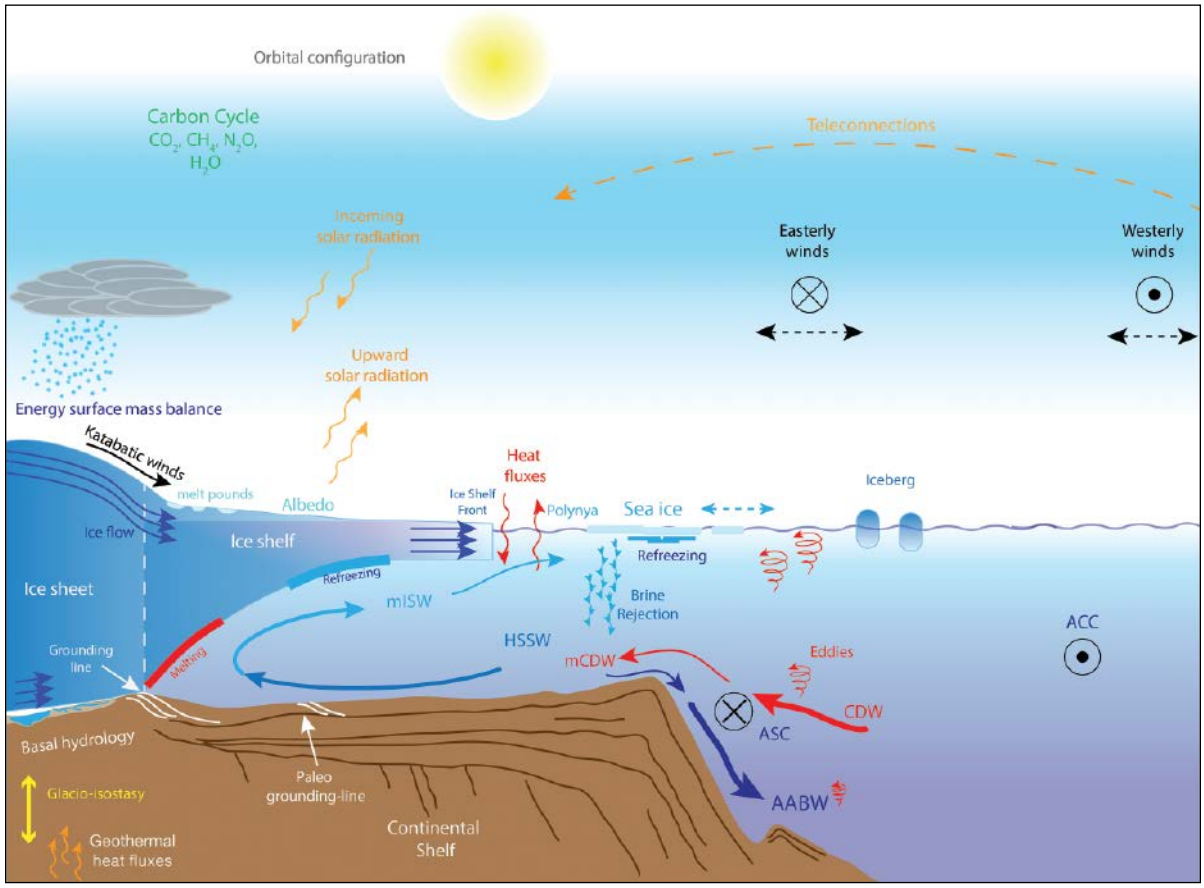

Fig. 1. Conceptual and simplified view of the Antarctic polar system, with the directions of the AABW, Antarctic Circumpolar Current (ACC), ASC, CDW, and High-Salinity Shelf Water (HSSW) marked. Also marked are modified CDW (mCDW) and modified Ice Shelf Water (mISW), so labeled because they represent distinct bodies formed by mixing currents. A circled X means flow into the image, and a circled dot means flow out of the image. The oceanic processes represented in 2-D view for the purpose of the illustration might not occur at the same locations on the continental shelf. Credit: Modified from Colleoni et al. *[2018]*

Together, the shipbound scientists sought answers to the following questions: What role does seafloor morphology play in the interaction between the Southern Ocean and the Antarctic ice sheet? Where exactly on the continental shelf do deep warm water, bottom water, and frigid ice shelf waters enter and flow out of the basins? What does the morphology of the seafloor reveal about past ice sheet dynamics and ocean circulation?t

The Ross Sea

The Ross Sea feeds into the Southern Ocean's Antarctic Bottom Water (AABW), the coldest and densest water mass in the world. As the seawater sinks, it ventilates and circulates the frigid waters of the abyss.

The southern boundary of the Ross Sea is the Ross ice shelf—Earth's largest body of floating ice permanently attached to landmass. The shelf starts floating at the grounding zone of some of the largest Antarctic ice streams. For a schematic of water currents below Antarctica's ice shelves and on the continental margin, see Figure 1.

Over the course of 30–40 million years, sediments accumulating on the ocean floor below the Ross Sea were preserved in the continental shelf basins, recording the historical advances and retreats of the Antarctic ice sheet. The Ross Sea is therefore a unique natural laboratory in which we can observe both modern and ancient sensitivities of frozen water masses—our cryosphere—to global climate warming. There, scientists can collect data relevant to ice melting, ocean freshening, circulation strength, seabed erosion and deposition by ice sheets, and oceanic bottom current flow.

Our Focus

The *OGS Explora* research team set out to gain a better understanding of the interaction between the Southern Ocean and the Antarctic ice sheet. To determine the role of seafloor morphology in this interaction, we collected evidence for both modern and ancient glacier pathways, West Antarctic ice stream activity, and the flow of the Antarctic Slope Current (ASC). We also had other targets of investigation: to locate Circumpolar Deep Water (CDW) inflows to the continental shelf as well as Ross Sea Bottom Water (RSBW) and supercold Ice Shelf Water (ISW) outflows from the Ross ice shelf (Figure 2).

Capturing ocean processes at different timescales was complex and challenging. Previous studies [*De Santis et al.*,

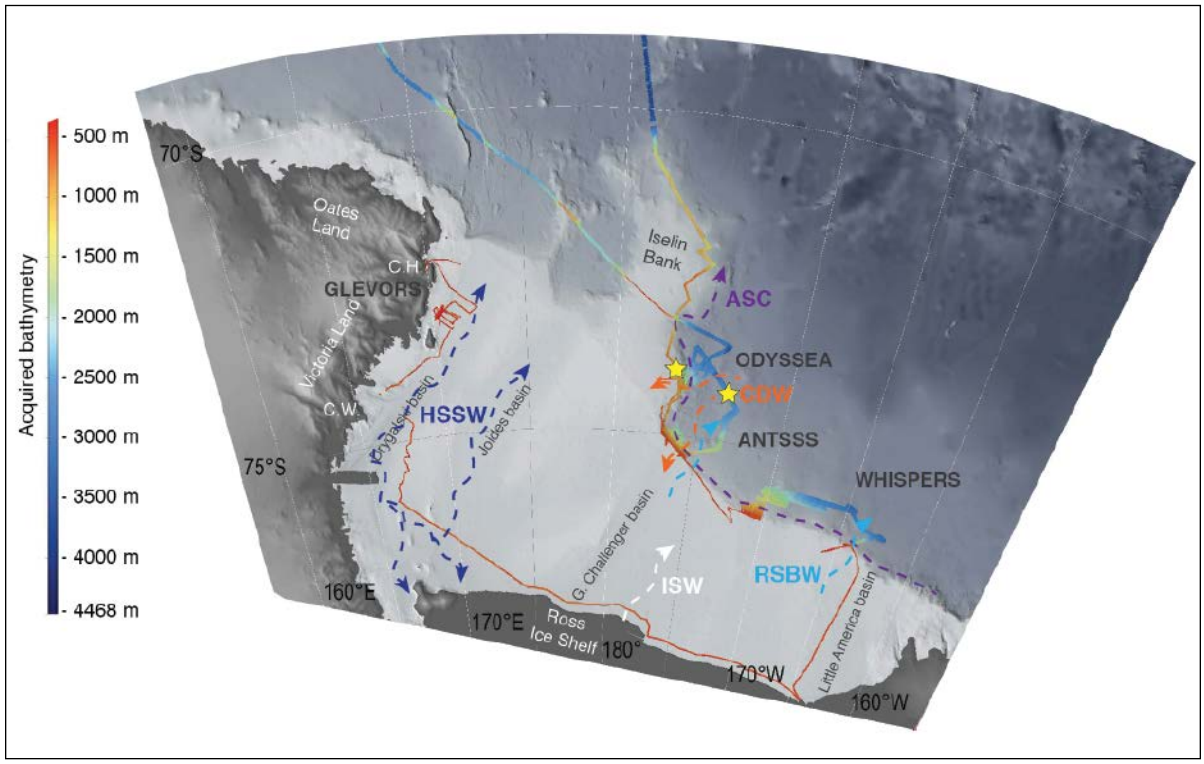

Fig. 2. A map of the 2017 OGS Explora *multibeam survey, showing the principal water masses that form and mix in the Ross Sea. ISW is the Ice Shelf Water, which forms by melting of the Ross ice shelf; HSSW is the High-Salinity Shelf Water, which forms in the continental shelf region. CDW is the Circumpolar Antarctic Deep Water, which encroaches on the continental shelf; RSBW is the Ross Sea Bottom Water, which forms by mixing of HSSW and CDW and flows downslope to feed the Antarctic Bottom Water (AABW); and ASC is the geostrophic Antarctic Slope Current, which flows westward around the Antarctic continental margin. The 2017* OGS Explora *expedition was funded by the Italian National Antarctic Research Program (PNRA) and included the West Antarctic Ice Sheet History from Slope Processes (WHISPERS), the Ocean Dynamics from the Sediment Drifts of the Ross Sea (ODYSSEA), and the Glacial Evolution in the North-Western Ross Sea (GLEVORS) projects and an additional survey in the Southern Ocean over the Macquarie triple point (not shown). Another project achieved during the 2017* OGS Explora *expedition was the Antarctic Ice Sheet Stability from Continental Slope Process (ANTSSS), which was funded by FP7/EU-EUROFLEETS-2. Data collected by the* OGS Explora *in 2017 were used in 2018 to help pick two sites for IODP Expedition 374 (stars). C.H. stands for Cape Hallett, and C.W. stands for Cape Washington; these are the sites of two photographs in this report. Credit: Daniela Accettella (OGS)*

1995; *Bergamasco et al.*, 2002; *Anderson et al.*, 2014; *Sauli et al.*, 2014] helped determine which sites to investigate. We measured ocean currents and water properties, and we located spots of water mass exchange across the edge of the continental shelf. One crucial part of the puzzle involved finding past imprints of these same ocean dynamic features in the sediments and paleomorphology of this continental margin.

The Tools We Used

We used profiling tools to record multibeam sonar and subbottom chirp survey data from the seabed, in combination with acoustic Doppler current profiles (Figure 1). To measure oceanic temperature and salinity variations with depth, we carried out oceanographic transects across the continental shelf edge as well as along the front of the Ross ice shelf using expendable bathythermographs and temperature–conductivity–depth profilers.

Reflection seismic profiles were collected near Victoria Land, across the continental shelf edge of Glomar Challenger Basin and Little America Basin, and at the base of the continental slope on the flank of Iselin Bank, where previous campaigns [*Bergamasco et al.*, 2002] had captured the RSBW and ISW outflow and the CDW inflow.

What We Found

We observed wedge-shaped sedimentary landforms created by the advances and retreats of glaciers at the grounding zone between Coulman Island and Cape Hallett (Victoria Land). We also saw sediment drifts formed by bottom currents in a fjord, over shallow banks, and along the continental slope. We collected sediment gravity cores and box cores within these features. In addition, we studied key areas where the heat and salt exchange between the open ocean and the Antarctic ice sheet continues today, as it likely has for millennia.

We found that the supercold ISW outflow originates at the front of the Ross ice shelf at about 180° longitude. We measured temperature, outflow dynamics, and other water properties as the ISW spilled over the continental shelf edge, between the Glomar Challenger Basin and the Iselin Bank. Similar measurements were made to

A view from the deck of the OGS Explora *during its 2017 expedition to the Ross Sea. The mountains and glaciers beyond Cape Hallett rise in the background. Credit: Laura De Santis*

locate the ASC and CDW intrusions onto the continental shelf.

We also imaged what looks to be imprints of past ocean dynamics and ice sheet meltwater pathways along and across the continental shelf edge, seen through seismic profiles and multibeam seafloor mapping (Figure 2). Preliminary analysis of the data revealed a variety of gullies along the continental shelf margin, possibly formed by changing hydrology patterns and different types of ice sheet flows, as well as by the exchange of ocean water masses across the continental shelf edge.

The data recorded during this expedition provide insights into how ocean dynamics influences the depositional and erosional processes of the continental margin as well as the ice sheet–ice shelf interaction with the ocean. They tell a story hundreds of thousands—up to millions—of years in the making, revealing the interconnectivity among such ice masses as the vast Ross ice shelf and Victoria Land glaciers. The data also reveal the evolution of the continental shelf, its interaction with marine and glaciological processes, and features of synoptic ocean dynamics. Such processes have affected the stability of the West Antarctic ice sheet for more than 5 million years [*Naish et al.*, 2009], particularly during warm climate periods, when ice sheets probably retreated or collapsed [*Pollard and DeConto*, 2009].

Forward Flow

The pioneering research initiated by the *OGS Explora* expedition is expected to launch a new generation of scientific projects. Data collected during the 2017 expedition were used to determine Ross Sea research sites for the 2018 International Ocean Discovery Program (IODP) Expedition 374. The 2018 expedition, which ran from 4 January through 8 March, collected cores and other data that will help those studying polar conditions to reconstruct the extent of the Antarctic ice sheet over the past 20 million years, during which Earth has undergone significant changes in atmospheric-oceanic circulation, atmospheric carbon dioxide concentration, and global temperature. Understanding how an ice sheet responds to global past climate fluctuations will help predict its vulnerability to ongoing and future global climate change.

Observations from the polar regions, where the effects of climate change on the environment are amplified, are still too sparse. Subsequent expeditions can complete the seabed mapping and sampling and measure the water column changes that signal continental shelf-to-slope heat exchange processes, ocean water mass mixing, and ice sheet dynamics. The polar scientific community is eager to improve its understanding and predictions of climate system evolution—a fundamental step toward defining effective policy actions to mitigate potentially adverse effects of global climate change.

Acknowledgments

We thank the PNRA and European EUROFLEETS funding programs; Capt. Franco Sedmak and crew; party chief Riccardo Codiglia; the technicians and scientific party of the expedition; Laura de Steur (Norwegian Polar Institute); Liu Yanguang (First Institute of Oceanography, Qindao, China); Robert McKay (Victoria University of Wellington, New Zealand), IODP Expedition 374 cochief officer; and Luca Gasperini (Consiglio Nazionale delle Ricerche), principal investigator of the PNRA/Macquarie project in the Southern Ocean. We also acknowledge IHS Markit, Paradigm, Schulmberger for Kingdom, Echos, and Vista academic free license.

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2018 AGU Union Medal, Award, and Prize Recipients Announced

AGU each year honors individuals for their outstanding achievements, contributions, and service to the Earth and space science community. AGU medals are the highest honors bestowed by the Union. They recognize individuals for their scientific body of work and sustained impact within the Earth and space science community. AGU Union awards and prizes recognize individuals who have demonstrated excellence in scientific research, education, communication, and outreach.

This distinguished group of honorees—scientists, leaders, educators, journalists, and communicators—embodies AGU's mission of promoting discovery in Earth and space science for the benefit of society.

On behalf of AGU's Honors and Recognition Committee, the selection committees, and AGU leaders and staff, we are pleased to present the recipients of AGU's 2018 Union medals, awards, and prizes.

We appreciate everyone who has shown support and commitment to AGU's Honors Program. Our dedicated volunteers gave valuable time as members of selection committees to choose this year's Union medal, award, and prize recipients. We also thank all the nominators and supporters who made this possible through their steadfast efforts to nominate and recognize their colleagues.

Celebrate at the Fall Meeting

We look forward to celebrating our honorees' profound contributions at this year's Honors Ceremony and Banquet, to be held on Wednesday, 12 December, at Fall Meeting 2018 in Washington, D. C.

Please join us in congratulating our esteemed class of 2018 Union honorees listed below.

Medals

William Bowie Medal
Daniel N. Baker, University of Colorado Boulder

James B. Macelwane Medal
Steven J. Davis, University of California, Irvine
Walter W. Immerzeel, Utrecht University
Isaac R. Santos, Southern Cross University
Drew L. Turner, The Aerospace Corporation, El Segundo, Calif.
Caroline Ummenhofer, Woods Hole Oceanographic Institution

John Adam Fleming Medal
Forrest S. Mozer, University of California, Berkeley

Walter H. Bucher Medal
Philip C. England, University of Oxford

Maurice Ewing Medal
Nicklas G. Pisias, Oregon State University

Robert E. Horton Medal
Dennis P. Lettenmaier, University of California, Los Angeles

Harry H. Hess Medal
Timothy L. Grove, Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology

Roger Revelle Medal
Isaac Held, Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration

Inge Lehmann Medal
Yoshio Fukao, Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

Charles A. Whitten Medal
David T. Sandwell, University of California, San Diego

Joanne Simpson Medal for Mid-Career Scientists
Olivier Bachmann, ETH Zürich
Endawoke Yizengaw, Boston College

Awards

Ambassador Award
Esteban Jobbágy, Universidad Nacional de San Luis and Consejo Nacional de Investigaciones Científicas y Técnicas
Rosaly M. C. Lopes, Jet Propulsion Laboratory, California Institute of Technology
Christopher M. Reddy, Woods Hole Oceanographic Institution

Edward A. Flinn III Award
Richard P. Hooper, Tufts University

William Kaula Award
Alberto Montanari, University of Bologna

Waldo E. Smith Award
M. Meghan Miller, UNAVCO

Charles S. Falkenberg Award
Rebecca Bergquist Neumann, University of Washington

Athelstan Spilhaus Award
C. Alex Young, NASA Goddard Space Flight Center

International Award
Giuliano Francesco Panza, Accademia dei Lincei and Accademia dei XL, Rome; and Olim University of Trieste

Excellence in Earth and Space Science Education Award
Mark A. Chandler, Center for Climate Systems Research

Africa Award for Research Excellence in Earth Science
Ahzegbobor Philips Aizebeokhai, Covenant University

Africa Award for Research Excellence in Space Science
Frédéric Ouattara, Université Norbert Zongo

Science for Solutions Award
Kyle Frankel Davis, Data Science Institute, Columbia University

Walter Sullivan Award for Excellence in Science Journalism–Features
Douglas Fox, High Country News

David Perlman Award for Excellence in Science Journalism–News
Shannon Hall, Freelance Science Journalist

Prizes

Asahiko Taira International Scientific Ocean Drilling Research Prize
Brandon Dugan, Colorado School of Mines

Climate Communication Prize
Michael E. Mann, Pennsylvania State University

By **Eric Davidson,** President, AGU; and **Mary Anne Holmes** (email: agu_unionhonors@agu.org), Chair, Honors and Recognition Committee, AGU

AGU Launches New Journal: *AGU Advances*

AGU is adding a new title to complement our distinguished portfolio of well-respected journals: *AGU Advances*. The new publication will be a highly selective "gold" open-access journal for the Earth and space science community (see http://bit.ly/what-is-gold).

How *AGU Advances* Is Different

AGU Advances will focus on publishing seminal research from across the Earth and space sciences and related interdisciplinary fields that has broad and immediate implications. This research will interest readers across the Earth and space science disciplines, the broader science community, policy makers, and the public. The new journal will publish novel, innovative research in the form of full-length papers and differentiate itself from other highly selective journals by being fully open-access, available to all to download, read, and share.

Beginning with the inaugural issue in late 2018/early 2019, *AGU Advances* will be published online only. Papers published in *AGU Advances* will be approximately 8,000 words each and include multiple figures and in-depth explanations of methods. Letters are approximately 4,000 words each and typically include half as many figures. Most *AGU Advances* papers will be further enriched by plain-language summaries and open-access commentaries to provide further context around the research, as well as by increased efforts to publicize papers with the media. *AGU Advances* will aim to publish at most around 150 papers per year to allow for this enrichment.

AGU's Portfolio of Journals

AGU, in partnership with Wiley, currently publishes an extensive, well-respected, highly cited, and frequently-reported-on portfolio of peer-reviewed scientific journals covering the breadth of research in the Earth and space sciences. *AGU Advances* will be AGU's 21st journal and our fifth open-access journal. The journals include *Geophysical Research Letters (GRL)*, which publishes letter-length papers that merit rapid review and high attention across the Earth and space sciences. *GRL* is AGU's largest journal and published more than 1,400 papers last year, indicating the broad popularity of this format and *GRL*'s strong reputation. *GRL* will remain AGU's leading letter-length journal, and *AGU Advances* will serve as a complement to both *GRL* and the rest of our portfolio.

Why This Journal? Why Now?

During the past century, our global society has experienced myriad challenges and opportunities. Advances in Earth and space science have played a huge role in our ability to understand and potentially overcome those challenges and to take advantage of those opportunities. Today that same society is depending on Earth and space science more than ever to ensure our ability to address what lies ahead.

Throughout our 100-year history, AGU has been committed to finding ways to accelerate scientific discovery and the exchange of knowledge. That commitment led to the development of our prestigious portfolio of journals and the position of authority AGU has today. As we prepare to mark our Centennial in 2019 (see http://bit.ly/AGU-100-intro), with the knowledge that the stakes are higher than ever, we intend for *AGU Advances* to build on the legacy and impact created by *GRL* and our 19 other distinguished titles, as it works to communicate the critical contributions Earth and space science makes to improving lives around the world.

Next Steps

The editorial board for *AGU Advances* will be formed from AGU's College of Fellows and will include representation from each of our sections. We are currently searching for an enthusiastic and forward-looking scientist to serve as the journal's inaugural editor in chief, who will work with our College of Fellows to form the full editorial team.

We are seeking an individual with a strong vision for the journal and for the future of Earth and space science. We are also working to hire a full-time Ph.D.-level managing editor, who will be responsible for supporting the authors and editors and for managing the commentaries.

We look forward to having you join us on this exciting new journey as we launch *AGU Advances*.

By **Chris McEntee** (email: agu_execdirector@agu.org), Executive Director/CEO, AGU

Evaluating the Accuracy of Seasonal Climate Predictions

Bathtub rings show the impact of sustained drought on Lake Mead in Nevada. Credit: 4kodiak/iStock/Getty Images Plus/Getty Images

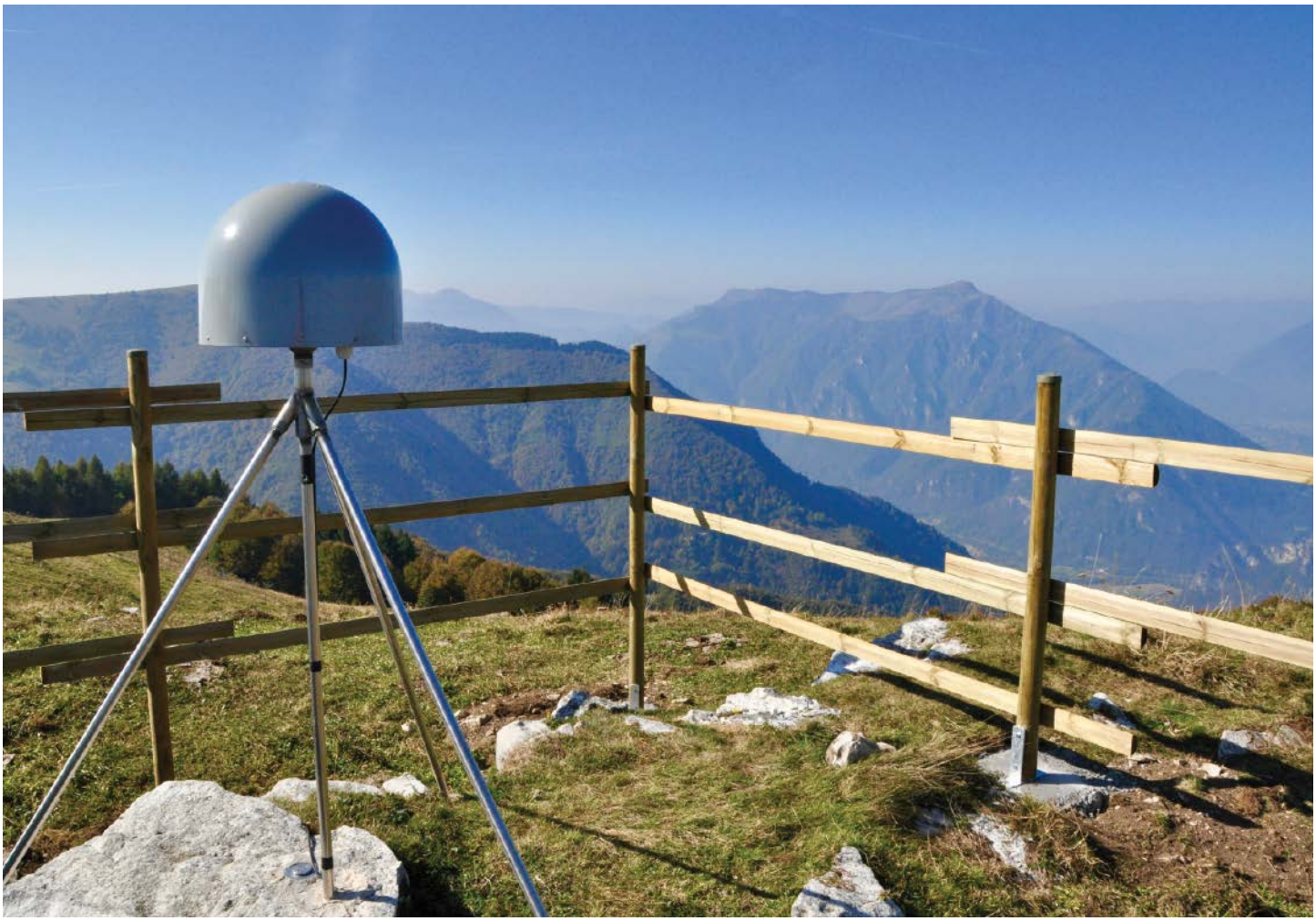
Seasonal climate predictions offer important information about anticipated regional conditions for periods extending beyond standard, long-range weather forecasts. Products summarizing these data, like the National Oceanic and Atmospheric Administration's 3-month outlooks, provide valuable guidance for governments and natural resource managers.

Seasonal predictions may be either deterministic—a "point forecast," which states that an event will occur at a specific place and time—or probabilistic—an indication of the likelihood that an event will occur. The accuracy of probabilistic forecasts depends on two characteristics: reliability, which is how consistently the predicted occurrence probabilities of an event match the corresponding observed occurrence frequencies, and resolution, which is the degree to which the observed frequencies differ from the long-term climatological frequency. Researchers recently discovered that a relationship exists between the probabilistic resolution and the deterministic forecasting skills but have been unable to fully explain it.

Yang et al. have conducted a detailed analysis of the relation between these skills to further investigate this puzzle. They first confirmed that under specific theoretical conditions, a monotonic relationship exists between deterministic and resolution forecasting skills. The researchers then analyzed historical general circulation model (GCM) outputs generated by the European ENSEMBLES project for the period spanning 1960–2005. Their findings indicate that the established relationship can also be confirmed using GCM forecast data.

The results, which offer a fresh perspective on two of the most intensely studied measures of forecasting skills, may have implications for improving our understanding of the properties of seasonally averaged variability in the atmosphere. The research also highlights the importance of not only evaluating the accuracy of seasonal predictions from a probabilistic perspective but also improving our understanding of how each skill is related to other types of forecasts. (*Journal of Geophysical Research: Atmospheres*, https://doi.org/10.1029/2017JD028002, 2018) **—Terri Cook, Freelance Writer**

Karst Groundwater Contributes to Deformation in Eastern Alps



A GPS station located at the top of an anticline hosting a karst aquifer, looking north toward the Belluno Valley and the Dolomites in Italy. Credit: Enrico Serpelloni

Most seismicity on Earth comes from the classic movement of tectonic plates sliding and colliding above the planet's mantle, but other, more localized forces can deform the crust as well. In a new study, *Serpelloni et al.* used GPS measurements from the Eastern Alps to monitor how rainfall and hydrological conditions contribute to ground deformation in this tectonically active region.

The Eastern Alps and the Dinarides feature areas characterized by classic karstic geography, in which water has gradually dissolved the limestone foundation that underlies the region's mountains and valleys. As a result, the terrain is marked by abundant sinkholes, caves, and aquifers. The researchers suspected that the karst, especially changes to aquifer water levels, might produce a measurable strain in the region.

Fortunately, the Eastern Alps are also rife with GPS stations that can precisely track ground displacement over time. Using data from these stations, the researchers applied a blind source separation algorithm that allowed them to isolate ground displacement in the region that was caused by forces other than classic plate tectonics. They eventually uncovered several different displacement signals across multiple spatial and temporal scales. In particular, the scientists found a nonseasonal signal showing horizontal deformation that correlated to rainfall in the region on monthly timescales. They attribute this signal to pressure changes resulting from fluctuating water levels within the vertical fractures of different karst systems.

The researchers say that together, the results demonstrate that this technique can be used to measure millimeter-scale transient deformations caused by changes to groundwater flow and precipitation. They also suggest that in addition to giving more accurate measurements of tectonics in karst regions, similar studies may be useful for measuring groundwater resources. (*Journal of Geophysical Research: Solid Earth,* https://doi.org/10.1002/2017JB015252, 2018) **—David Shultz, Freelance Writer**

How Mesquite Trees Gain a Competitive Edge in Arid Arizona

Water is scarce in the Santa Rita Experimental Range in southern Arizona. The range receives less than 50 centimeters of precipitation each year, and much of that falls during the summer monsoon season from July to September. However, the aridity does not deter plant life from taking root and thriving in the baking Sun.

To survive the harsh conditions, the vegetation in the region uses savvy adaptations to make the best use of water when it is available. Hydraulic redistribution, which refers to a plant's ability to relocate water from wet to dry soil layers using its roots as conduits, is one such technique. Scientists have observed this phenomenon in plants spanning climates and ecosystems around the world. In the savannas of Santa Rita, mesquite trees are masters of the practice.

Lee et al. explored how water in the savanna ecosystem is partitioned throughout the year and how mesquites use hydraulic redistribution to sequester some of that water for their own use. The researchers developed a "shared resource model" to evaluate how the trees and bunchgrass in the understory compete for the limited soil moisture. They validated the model with sap flow data collected in the field. The heat flow between sensors embedded in the roots serves as a proxy for flux of water in the tree, which is a measure of hydraulic redistribution.

The research showed that 83% of the water entering the ecosystem evaporated from the soil or escaped from plants as they absorbed carbon dioxide from the atmosphere, a process known as transpiration. The remainder of the water was stored in the soil and used during the following dry season.

Of the water in the soil, 13% was transported to deep soil layers through hydraulic redistribution in the mesquite roots. More than half of that water later returned to shallow soil layers during the dry season. The researchers found, however, that the return of the water to the surface soil did not significantly benefit the understory grass, which indicated that mesquites use hydraulic redistribution to gain a competitive advantage over the neighboring bunchgrass.

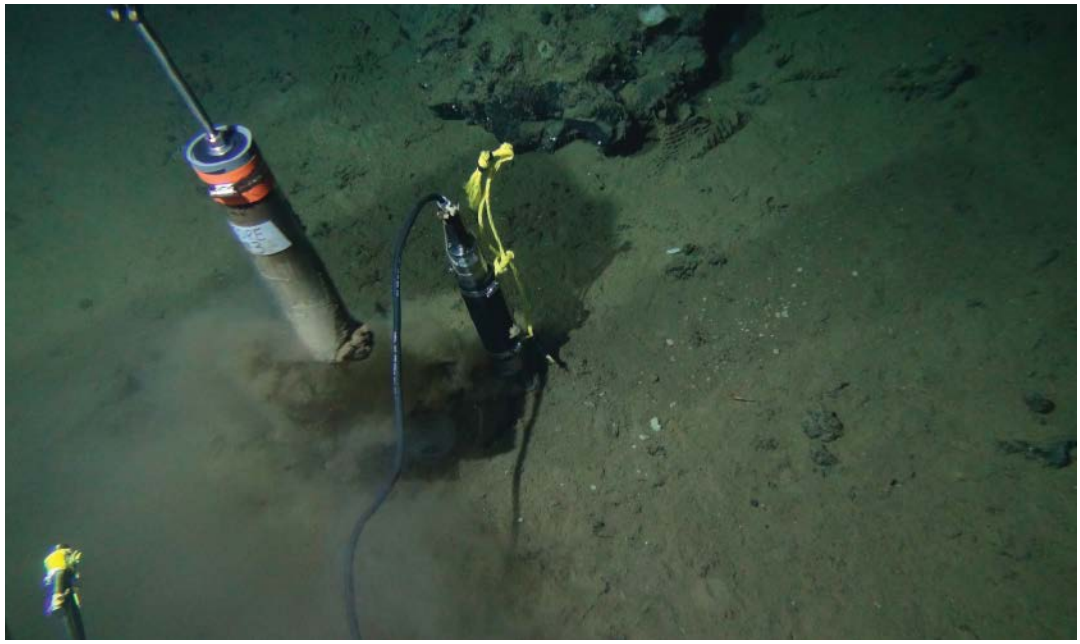
*Mesquite trees (*Prosopis velutina*), a common species in the savannas of southern Arizona, use hydraulic redistribution to partition water in their arid habitat. Credit: Praveen Kumar*

The study offers novel insights into the mechanisms that drive the movement of water between plants and the environment. It also further elucidates how plants survive in the harsh conditions of arid and semiarid environments. (*Water Resources Research*, https://doi.org/10.1029/2017WR021006, 2018) **—Aaron Sidder, Freelance Writer**

Life and Death in the Deepest Depths of the Seafloor

Scientists are plumbing the depths of the seafloor in search of answers about necromass—the decomposing remains of dead organisms—and its potential to generate life-sustaining energy for microorganisms that have become buried in seafloor sediments, a phenomenon that is poorly understood.

In a new study, *Bradley et al.* looked at populations of microbes living in the sediments underlying the South Pacific Gyre (SPG), a vast expanse of ocean between Australia and South America. Buried in layers of sediment on the seafloor, these microbes are likely dominated by heterotrophs, organisms that are unable to make their own food and must consume the remains of other living things to survive, just as humans, fellow heterotrophs, rely on plants and animals for food.



A photograph taken from Alvin, *a manned deep-ocean research submersible, of sediment coring on the ocean floor at Dorado Outcrop in 2014. Credit: NSF OCE 1130146 and the National Deep Submergence Facility*

The SPG is the most oligotrophic ocean region on Earth, which means that it is poor in nutrients but rich in dissolved oxygen. With no light and few nutrients available to them, heterotrophs in this environment often feed on energy generated through oxidizing the remains of cells and other organic materials. Like all living things, these organisms use energy at rates that meet their power demand. However, the extraordinarily low concentrations of organic materials in sediments in the SPG severely restrict the breathing rates of the heterotrophic organisms found there, which means that this area of the seafloor contains more dissolved oxygen than elsewhere.

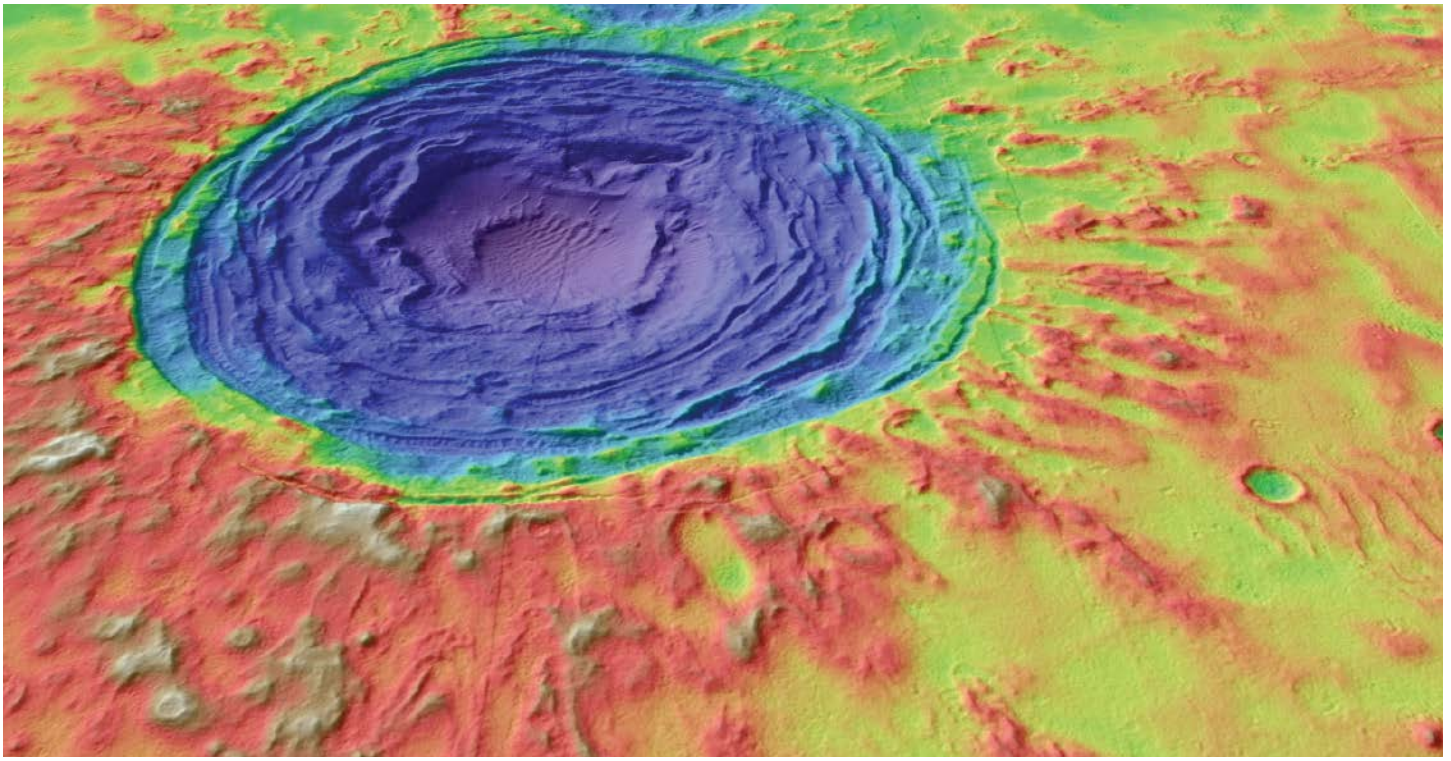
By analyzing sediment samples from the SPG and applying a mathematical model, the team found that the oxidation of necromass produced within the upper 3 meters of sediment produces just 0.02% of the total power demand of the microbial community in that layer. This number continued to decrease as the scientists probed deeper into the sediment, where the microbial populations are much sparser.

On the other hand, the team found that the oxidization of allochthonous material (ancient organic material that has been buried in place in the sediments), as well as of hydrogen, seems to have a much greater impact on the supply of power required by the microbial community.

The team found similar results on a global scale: In layers of sediment less than 10,000 years old, oxidized necromass met 13% or less of the microbial communities' power needs. In older layers, its contribution was inconsequential.

This study sheds light on one of nature's murkiest environments—deep below the seafloor—and identifies key sources of power that support life and entire ecosystems in these globally expansive but ultraextreme habitats. (*Journal of Geophysical Research: Biogeosciences*, https://doi.org/10.1002/2017JG004186, 2018) **—Sarah Witman, Freelance Writer**

Tracing the Steps of Hydrothermal Activity in Hrad Vallis, Mars



False-color image of a lava rise pit formed by gradual thickening of lava around an initially high standing topographic obstacle in Hrad Vallis on Mars. Warm colors indicate relatively high elevations, and cool colors represent lower elevations. Credit: University of Arizona, NASA

Much of our planet's recent history is documented in books, letters, photographs, and films. To supplement these human-made records and delve even further back, we rely on nature's relics—tree rings, geologic formations, and the evolving genetic makeup of animals—to better understand Earth's history.

Human exploration of Mars has unfolded in much the same way. By observing the planet through telescopes, studying Martian rocks and meteorites, and collecting data via satellite missions, scientists across many disciplines have been able to piece together some of the natural history of the Red Planet, dating back millions of years.

On the basis of these types of records, scientists believe that at some point, flooding and volcanic activity formed a network of valleys across Mars. Knowing more about the magnitude and timing of these events could reveal more about the planet's natural history and help identify regions that might be hospitable to microbial life.

Hamilton et al. studied a 370-meter-deep, 800-kilometer-long valley called Hrad Vallis. Named after the Armenian word for Mars, Hrad Vallis is young in terms of geologic time; scientists believe that it formed during the Amazonian age, or roughly within the past 3 billion years.

Using a combination of mathematical models and geologic mapping, the researchers found that Hrad Vallis was probably formed by an intrusion—underground magma that cooled and solidified before reaching the surface—which triggered a flood of water. This most likely was followed by lava flowing along the surface and forming a flat-topped mound called a lava rise plateau, dotted with small depressions called lava rise pits, then by more intrusions and flooding. A pattern of lava flows interspersed with flooding events has been seen elsewhere on Mars, suggesting that other formations from the Amazonian were also born of multistage processes, as opposed to single events.

The researchers also found that some of the lava flows forming Hrad Vallis may have interacted violently with ice deposits at the surface, creating a landscape of depressions, lakes, and sinkholes. This type of landscape, called thermokarst terrain, occurs on Earth in Arctic and sub-Arctic regions when permafrost melts. Amid this lava-ice interaction, it's possible that a warm, moist environment could have formed, providing a habitat capable of sustaining life, at least temporarily.

Furthermore, the team found that at least one of the lava flows involved in the formation of Hrad Vallis might have been similar to a smooth, lobate lava called inflated pahoehoe. If this is true, it would be the best example yet of such a lava flow found on Mars.

On Earth, pahoehoe is a common eruption style in which the volume of lava produced per day is quite low, which implies that the Martian eruptions may have lasted for years to decades.

These findings not only enrich our understanding of Mars's past geological transformations but also bring many aspects of its current landscape to light. (*Journal of Geophysical Research: Planets,* https://doi.org/10.1029/2018JE005543, 2018) **—Sarah Witman, Freelance Writer**

Atmospheric Sciences

Assistant/Associate Professor in Regional Climate Modeling at Indiana University

The Department of Earth and Atmospheric Sciences at Indiana University Bloomington invites applications for a tenure-track position in climate modeling to begin in Fall 2019. Applicants with strengths in a general area of earth system modeling, climate dynamics, or land-atmospheric coupled models are encouraged to apply. Experience with regional climate downscaling and high-performance computing will be considered strong assets. The successful candidate will establish an internationally recognized, externally funded academic research program, and have a strong interest in graduate and undergraduate instruction including mentoring of M.S. and Ph.D. student research. Service to the department, college, and university is expected.

Applicants must have a Ph.D. in Atmospheric Sciences or a related field prior to employment. To ensure full consideration, applications should be submitted by Oct 15, 2018 but they will continue to be considered until the position is filled. Interested candidates should review the job description and submit application materials online at http://indiana.peopleadmin.com/postings/6515. Questions about the position should be directed to: Dr. Chanh Kieu, Search Committee Chair (ckieu@indiana.edu). Details about the Department, IU Environmental Resilience Institute, and Bloomington can be found at http://geology.indiana.edu/department/index.html. Indiana University is an equal employment and affirmative action employer and a provider of ADA services. All qualified applicants will receive consideration for employment without regard to age, ethnicity, color, race, religion, sex, sexual orientation, gender identity or expression, genetic information, marital status, national origin, disability status or protected veteran status. Enhancing diversity within our faculty and students is an important aspect of department and college strategic planning.

Assistant Professor of Earth and Atmospheric Sciences (Hydrogeology/Groundwater Modeling)

Applications are invited for a tenure track position as Assistant Professor in the Department of Earth and Atmospheric Sciences at the University of Nebraska-Lincoln. The position forms part of a cluster hire (Climate Change: Impacts, Adaptation, and Mitigation) that involves multiple departments in the College of Arts and Sciences. The successful candidate will be expected to participate in teaching and curricular development of undergraduate and graduate courses, to advise and direct graduate students, and to develop a rigorous research program that is supported by external funding. It is expected that the research program will focus on relationships between the hydrosphere and climate. The ability to contribute to multidisciplinary water and climate research efforts in the department and college will be considered as an advantage. The candidate should demonstrate strong potential for research and teaching and must hold a Ph.D. in Geology, Hydrogeology, or a related field at the time of appointment.

The Department of Earth and Atmospheric Sciences offers B.S. degrees in Geology and Meteorology-Climatology, as well as M.S. and Ph.D. degrees in Earth and Atmospheric Sciences. Additional information about our department can be found on our web site: http://eas.unl.edu.

To apply, go to http://employment.unl.edu/postings/60181 and complete the 'faculty/administrative form'. Applicants must attach a cover letter, curriculum vitae, statements of research and teaching interests, and names of at least three references via the above website. We will begin to review applications on November 23, but the position will remain open until it is filled.

As an EO/AA employer, qualified applicants are considered for employment without regard to race, color, ethnicity, national origin, sex, pregnancy, sexual orientation, gender identity, religion, disability, age, genetic information, veteran status, marital status, and/or political affiliation. See http://www.unl.edu/equity/notice-nondiscrimination.

For further information, contact Dr. Richard Kettler, Search Committee Chair by email, phone, or mail at: rkettler1@unl.edu, 1-402-472-0882; Department of Earth & Atmospheric Sciences, University of Nebraska-Lincoln, 126 Bessey Hall, Lincoln NE 68588-0340.

Professional Assistant Professor in Atmospheric Science

The Department of Physical and Environmental Sciences at Texas A&M University-Corpus Christi is inviting applications for a non-tenure track position as Professional Assistant Professor in Atmospheric Science. Professional Assistant Professors are full time teaching faculty with the potential for promotion to the rank of professional associate and professional professor positions. The successful candidate will teach multiple courses in atmospheric sciences, support outreach activities and recruiting students, take a lead role in academic advising and participate in curriculum development, and oversee the coordination of Atmospheric Science program as a program coordinator. Demonstrated excellence in teaching courses in atmospheric science is required. Preference is given to applicants who show evidence of the skills

required for recruiting students and outreach activity and the skills required for advising/mentoring undergraduate students. Ph.D. in Atmospheric Science, Meteorology or a related field is required at the time of the appointment.

Texas A&M University-Corpus Christi (TAMUCC) is a rapidly growing doctoral research university, located on the beautiful coast of the Gulf of Mexico. The Department of Physical and Environmental Sciences at TAMUCC offers undergraduate degrees in Atmospheric Science, Environmental Science, Geology, Physics, and Chemistry as well as PhD degrees in Coastal and Marine System Science and M.S. degrees in Environmental Science, Coastal and Marine System Science, and Chemistry. Further Information about the Department of Physical and Environmental Sciences can be found at http://pens.tamucc.edu/.

TO APPLY: http://hr.tamucc.edu/Job_Opportunities/index.html

Applicants must submit a cover letter, curriculum vitae, a statement of teaching philosophy, and names of at least three references via the above website. The position will remain open until a finalist is selected. Applicants are encouraged to apply by December 1, 2018. The preferred starting date for this position is August 19, 2019.

Senior Research Scientist-Atmospheric Science

FM Global is a leading property insurer of the world's largest businesses, providing more than one-third of FORTUNE 1000-size companies with engineering-based risk management and property insurance solutions. FM Global helps clients maintain continuity in their business operations by drawing upon state-of-the-art loss-prevention engineering and research; risk management skills and support services; tailored risk transfer capabilities; and superior financial strength. To do so, we rely on a dynamic, culturally diverse group of employees, working in more than 100 countries, in a variety of challenging roles.

The person in this position will be responsible for planning and conducting research in atmospheric hazard modeling to evaluate, develop, and implement new techniques and models for tropical/extra tropical/severe convective storms, hail, tornadoes, and extreme precipitation that can lead to property losses.

Work will include preparing reports and presentations describing the results of studies completed or in progress, the relevance of the results for loss prevention and risk management, and the development and implementation of loss prevention and mitigation techniques; and developing plans for strategic research that will lead to measurable, significant improvements in the ability to estimate future property losses.

The position requires a PhD degree and a solid research record in atmospheric science or related field demonstrating a broad physical understanding of atmospheric processes and experience using and combining large atmospheric data sets in various formats; strong programming and numerical analysis skills. Applicants must have demonstrated project management abilities and excellent written and verbal communication skills.

Previous experience with modeling wind and precipitation from tropical cyclones, analysis of related data, and generation of synthetic event sets is a plus. Desired to have a sound background in statistics and previous experience with high-performance computing.

The job title depends on qualifications and experience.

Apply at https://jobs.fmglobalcareers.com/job/norwood/senior-research-scientist-atmospheric-science/474/6907908

Geochemistry

Assistant Professor of Geochemistry-Earth/Planetary Processes

The Department of Earth, Environmental & Planetary Sciences at Brown University (http://www.brown.edu/academics/earth-environmental-planetary-sciences/) invites applications for a tenure-track faculty appointment in geochemistry. Any analytical, experimental and theoretical/computational approach to understanding the origin and chemical evolution of the Earth and planets will be considered. Some examples include, but are not limited to, cosmochemistry, planetary petrology, non-traditional stable isotope geochemistry, early Earth evolution, volcanology, and interactions of planetary materials with hydrospheres and atmospheres. Preference will be given to candidates whose strengths complement departmental research expertise in Geochemistry and Petrology, Planetary Geoscience, Geophysics, and Climate and Environment. We seek scientists whose research integrates field observations, geochemical analyses, experimental studies, and geochemical theory and/or modeling. We are interested in scientists whose research transcends traditional boundaries in geochemistry, such as between high-temperature and low-temperature geochemistry, geochemistry and geophysics, and terrestrial and planetary. The successful candidate will maintain an active, externally-funded research program and enjoy a commitment to teaching at both undergraduate and graduate levels. Appointment will be at the Assistant Professor level.

Apply at: http://www.interfolio.com/apply/34413

Geochemistry of Near Surface Environments

The Department of Earth Sciences at the University of Minnesota-Twin Cities invites applications for a tenure-track faculty position in Isotope Geochemistry and/or Analytical Geochemistry of Near Surface Environments at the assistant professor level. Exceptional candidates at the associate professor level will also be considered. We seek a colleague who creatively uses isotopic and/or analytical approaches to understand processes and changes in near surface environments in modern and ancient systems, including the atmosphere, hydrosphere, cryosphere, biosphere, and/or the upper crust. Successful applicants will be expected to contribute to a diverse research and teaching community in the Department of Earth Sciences through the development of a vigorous, internationally recognized and externally funded research program, through teaching courses at the undergraduate and graduate levels, and through service in the department, college, and university. The Department of Earth Sciences is part of the College of Science and Engineering and houses research programs as well as state-of-the-art analytical facilities spanning a broad spectrum of Earth Science disciplines (further information is available at: http://www.esci.umn.edu).

Applicants must have a Ph.D. in the geosciences or a related field at the time of appointment. Applicants should submit a cover letter, curriculum vitae, research statement, teaching statement, names and contact information of three references, and, if applicable, a list of any planned presentations at conferences in fall of 2018. These materials must be submitted online

- http://www1.umn.edu/ohr/employment/
- search for Requisition Number 325790

Appointment may begin as early as August 2019. Review of applications will begin on Oct. 15, 2018, and continue until the position is filled. For further information or questions, please contact R. Lawrence Edwards, Chair of the Search Committee at edwar001@umn.edu.

The University of Minnesota values a diverse faculty, which fosters a richness of perspectives and an inclusive environment, and whose members serve as role models for a diverse student body. The University provides equal access to and opportunity in its programs, facilities, and employment without regard to race, color, creed, religion, national origin, gender, age, marital status, disability, public assistance status, veteran status, sexual orientation, gender identity, or gender expression. The University supports the work-life balance of its faculty.

Tenure-Track Faculty Position Geochemistry of Near-Surface Processes, Boston College

The Department of Earth and Environmental Sciences at Boston College invites applications for a tenure-track faculty position at the rank of Assistant Professor. We seek candidates with expertise in low-temperature geochemistry with application to Earth's near-surface environment in the context of global change. The successful candidate will be expected to develop a vigorous externally funded research program integrated with excellence in teaching at both the undergraduate and graduate levels. The candidate should have research interests compatible with those of the current faculty in the Department of Earth and Environmental Sciences, including, but not limited to: understanding modern processes related to the exchange of water, carbon, and pollutants between the atmosphere, the oceans, the terrestrial hydrosphere, land surface, and urban systems, or reconstructing/understanding ancient environments and climates. We particularly encourage applicants whose research uses stable isotopes, integrates field-based research, and/or crosses traditional disciplinary boundaries in the sciences, thereby having the potential to also conduct innovative research within the forthcoming Schiller Institute for Integrated Science and Society at Boston College.

Applicants must hold a Ph.D. in the geosciences or a related field at the time of appointment. Complete applications should be submitted online at: https://apply.interfolio.com/53801. Review of applications will begin on November 1, 2018. Inquiries may be directed to Prof. Jeremy Shakun, Search Committee Chair (jeremy.shakun@bc.edu), or Ethan Baxter, Department Chair (ethan.baxter@bc.edu).

Boston College is an Affirmative Action/Equal Opportunity Employer and does not discriminate on the basis of any legally protected category including disability and protected veteran status.

Hydrology

Research Scientist – Hydrology

FM Global is a leading property insurer of the world's largest businesses, providing more than one-third of FORTUNE 1000-size companies with engineering-based risk management and property insurance solutions. FM Global helps clients maintain continuity in their business operations by drawing upon state-of-the-art loss-prevention engineering and research; risk management skills and support services; tailored risk transfer capabilities; and superior financial strength. To do so, we rely on a dynamic, culturally diverse group of employees, working in more than 100 countries, in a variety of challenging roles.

FM Global Research is the driving force behind our property loss-prevention engineering and understanding of the hazards our clients face. FM Global has been the leader in property loss-prevention research for more than 175 years.

As part of our research department, you'll work alongside other researchers and independently to understand emerging property loss-prevention hazards, quantify real-world scenarios, and develop new ways to protect against today's property-loss threats. You'll also work on implementation, evaluation, and development of techniques—including computer models and experiments—and present your findings to make strategic and beneficial advancements in risk mitigation.

As part of our research division, you'll work alongside a unique group of scientists across engineering, earth, hydrological, and atmospheric sciences to protect the value of FM Global's clients' businesses by developing methods to identify hazards, assess risk, and produce loss prevention solutions that are efficient and cost-effective.

Interested in a career with our Structures and Natural Hazards group? We have an opening for planning and conducting research on flood, and subsequent property losses.

Position requires a PhD degree, and a research record in hydrology or related field. Candidates are expected to have:

- knowledge of catchment-based, lumped, semi-distributed, and distributed hydrologic models; understanding of modeling principles, and model setup, calibration and validation; experience with collecting, processing, and analyzing data, and in developing and implementing new techniques;
- solid background in probability and statistics; proven technical programming experience; and GIS skills.

Applicants must have demonstrated project management abilities and excellent written and verbal communication skills. The job title depends on qualifications and experience.

Apply at https://jobs.fmglobalcareers.com/job/norwood/research-scientist-hydrology/474/5203203

Interdisciplinary

ASSISTANT PROFESSOR IN COASTAL RESILIENCY

Position Description

The Rice University Department of Civil and Environmental Engineering invites applications for a tenure track assistant professor position in the area of Coastal Resiliency to begin July 2019. Exceptional candidates at higher ranks also will be considered. We seek candidates with expertise and interest in interdisciplinary research that contributes to enhancing the resilience of urban communities and infrastructure systems to the impacts of coastal natural hazards and climate change.

Requirements, Application Materials and Deadline

Applicants must have earned a Ph.D. degree in Civil / Coastal / Environmental Engineering or a related field, demonstrate excellence in research, display distinction (or potential for distinction) in teaching, and be able to collaborate across disciplines. Requested materials include a cover letter that summarizes qualifications for this position; curriculum vitae including academic and professional experience and a list of publications; statements of research and teaching interests; and the names and contact information of three (3) references.

Review of applications will begin November 1, 2018. For full candidacy details and to apply, please visit the Rice Application Portal via this link: http://jobs.rice.edu/postings/16586.

Rice University is an Equal Opportunity Employer with commitment to diversity at all levels and considers for employment qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national or ethnic origin, genetic information, disability, or protected veteran status.

Assistant Professor in Organic Biogeochemistry

As part of a larger investment to create a new Science of Living System Initiative, the Department of Geosciences at Auburn University invites applications for a new tenure-track Assistant Professor position in Organic Biogeochemistry, beginning in the Fall Semester 2019. Applicants are expected to hold a Ph.D. in geosciences or a related field at the time employment begins. Specialties may include, but are not limited to 1) investigating biogeochemical processes occurring at or near the Earth's surface across the broad spectrum of interfaces ranging in scale from global to molecular; 2) the role of life in the transformation and evolution of Earth's biogeochemical cycles; 3) surficial biogeochemical systems and cycles, including their modification through climate change and human activities; 4) mineralogy and biogeochemistry of earth materials; 5) geomicrobiology and biomineralization processes and their applications in environmental remediation; and 6) environmental health related to air, soil, and water pollution. We seek a dynamic individual who will play a leadership role in propelling our new interdisciplinary Earth System Science PhD Program. Collaborative research programs that are regional or global in scope are currently active with faculty in the College of Sciences and Mathematics, School of Forestry and Wildlife Science, College of Engineering, and

College of Agriculture. New faculty with expertise in Organic Biogeochemistry will complement the University's considerable existing expertise in the areas of hydrogeology, climate change/paleoclimate sciences, environmental geochemistry, and sedimentary geology. The successful candidate is expected to develop a vigorous, externally funded research program, publish scholarly work, and advise graduate and undergraduate students. The successful candidate will have duties that include teaching graduate and undergraduate courses based on his/her expertise. The candidate selected for this position must meet eligibility requirements to work in the United States on the date the appointment is scheduled to begin (August 2019) and must be able to continue working legally for the proposed term of employment. The candidate must possess excellent written and interpersonal communication skills.

Applications must include curriculum vitae, letter of application describing professional experience, research and teaching interests, copies of official transcripts, and the names and contact information of three professional references. To apply please go to http://aufacultypositions.peopleadmin.com/postings/3076, complete the online form and upload the required application documents.

Applicants are encouraged to visit the AU website to learn more about Auburn University and Geosciences program http://www.auburn.edu/academic/cosam/. Review of applications will begin December 7th, 2018 and will continue until a candidate accepts appointment.

Auburn University is an EEO/Vet/Disability employer.

Assistant Professor of Earth System Science (tenure track): Global change impacts on terrestrial ecosystems

The Department of Earth System Science (ESS) at the University of California, Irvine, invites applications for a tenure-track faculty position focused on the effects of global environmental change on natural or managed terrestrial ecosystems. We are particularly interested in applicants who are working to quantify, understand and predict the impacts on land surface structure and function, including vegetation dynamics, hydrology or biogeochemistry. We welcome applications from researchers who are using a range of approaches, such as manipulations, in-situ or remotely-sensed observations, or process modeling. The successful applicant will have a strong research agenda, a commitment to excellence in teaching, and enthusiasm for joining a collegial, cross-disciplinary department.

UC Irvine's ESS department was founded to explore the global environmental changes that occur on human time scales. The department has 24 full time faculty from diverse backgrounds and a goal of understanding how human society is changing the land, atmosphere, oceans and cryosphere (http://www.ess.uci.edu/). UCI is a Minority Serving Institution (MSI), a Hispanic-Serving Institution (HSI) and an Asian American and Native American Pacific Islander-Serving Institution (AANAPISI). These federal designations align with UCI's aspiration to be a national leader and global model of inclusive excellence.

Candidates must have a doctoral degree. Apply online at https://recruit.ap.uci.edu/apply/JPF04979 or contact facultysearch@ess.uci.edu. Review of applications will begin December 21, 2018.

The University of California, Irvine is an Equal Opportunity /Affirmative Action Employer advancing inclusive excellence. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability, age, protected veteran status, or other protected categories covered by the UC nondiscrimination policy. A recipient of an NSF ADVANCE award for gender equity, UCI is responsive to the needs of dual career couples, supports work-life balance through an array of family-friendly policies, and is dedicated to broadening participation in higher education.

Faculty Position in Geological Engineering, Missouri University of Science and Technology

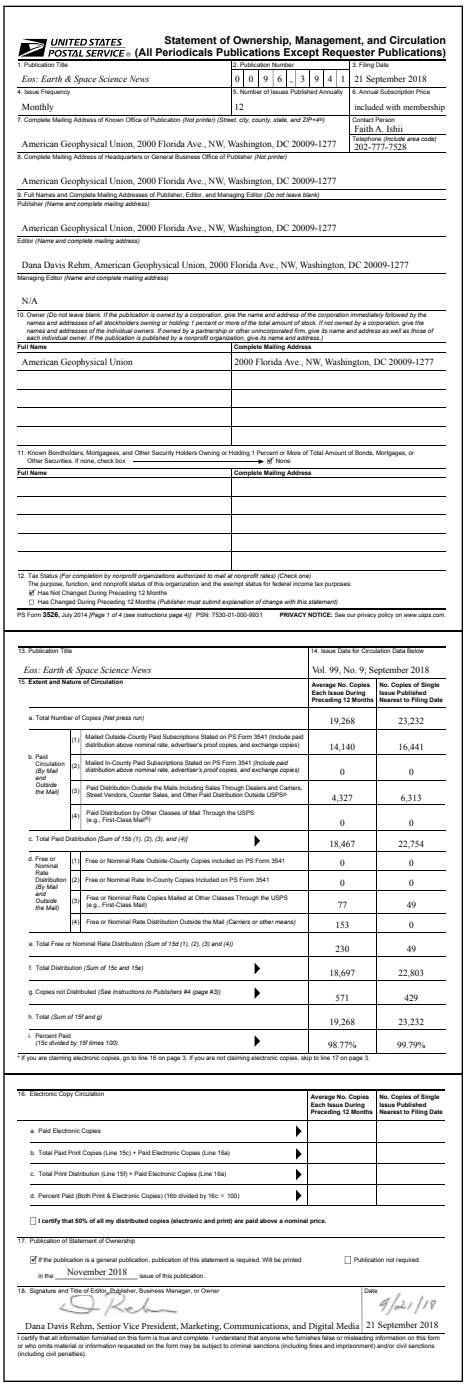
Rolla, Missouri–https://ggpe.mst.edu/

The Department of Geosciences and Geological and Petroleum Engineering (GGPE) at Missouri S&T is seeking outstanding applicants for a tenure track, open rank faculty position in Geological Engineering specializing in 'Big Earth Data'. We seek a candidate with expertise in Big Earth Data, including possible areas such as Geo-computing (machine learning, artificial intelligence, programming, etc.), Geoanalytics, Geostatistics, and Earth modeling. Preference will be given to applicants who specialize in the collection, synthesis, and analysis of large datasets applied to topics such as geohazards, renewable energy, geoenvironmental and water resources, geomechanics, and space/planetary systems. Successful candidates will be expected to have strong commitments to (a) contributing to the departmental and college research efforts, (b) high-quality teaching both at the undergraduate and graduate levels on topics such as computer applications in earth science and engineering and statistics for geologists and engineers, (c) service in the applicant's professional community and our institution, and (d) increasing the diversity of both the student body and faculty. Applicants must hold a Ph.D. in geological engineering or a closely related field by the appointment start date. Eligibility for professional engineering registration is considered an asset.

Missouri S&T is one of the nation's leading research universities. Located about 100 miles west of St. Louis. Missouri S&T is an accessible, safe and friendly campus surrounded by Ozark scenery. The campus is located in Rolla, Missouri, which is also home to the USGS Center of Excellence for Geospatial Information Science and the National Geospatial Technical Operations Center, which provide many opportunities for collaboration with USGS scientists. The GGPE Department has 21 tenured/tenure-track faculty and approximately 600 students (roughly evenly split between graduate and undergraduates). All of our programs offer B.S., M.S. and Ph.D. degrees. The ABET-accredited Geological Engineering program has approximately 80 undergraduate students, 50 on-campus graduate students and 65 off-campus graduate students. More information about the department and further details on required and desired attributes, skills and characteristics of the successful candidate can be found at http://ggpe.mst.edu/.

Interested candidates should electronically submit their application consisting of: 1) a cover letter, 2) a current curriculum vitae, 3) a research statement, 4) a teaching statement, 5) a diversity statement, and 6) complete contact information for at least four references to Missouri S&T's Human Resources Office at: http://hr.mst.edu/careers/academic/ using Reference Number 28023. Acceptable electronic formats are PDF and MS Word. Applications will be reviewed as they are received and the review of applications will continue until the position is filled. For full consideration, applicants must apply by November 25, 2018. For more information prior to submitting an application, please contact the Search Committee Chair, Dr. Katherine Grote at grotekr@mst.edu.

Missouri S&T is an AA/EEO employer and does not discriminate on the basis of race, color, national origin, ancestry, religion, sex, pregnancy, sexual orientation, gender identity, gender expression, age, disability, protected veteran status, or any other status protected by applicable state or federal law. Females,



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I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including civil penalties).

minorities, and persons with disabilities are encouraged to apply. The university participates in E-Verify. For more information on E-Verify, please contact DHS at: 1-888-464-4218.

Tenure-Track Assistant Professor at University of Rochester, Dept. of Earth and Environmental Sci.

The Department of Earth and Environmental Sciences at the University of Rochester will be hiring two tenure-track Assistant Professors in the general fields of Climate Science and Surface Processes/Geomorphology. While the department welcomes all applicants whose research lies in these general fields, we are particularly interested in candidates who bridge Solid Earth and Climate Science disciplines. In Surface Processes/Geomorphology, we encourage interdisciplinary applicants who focus on the critical zone between solid Earth systems and the Earth's fluid envelopes. In Climate Science, we encourage applicants whose research focusses on the Carbon Cycle with emphasis on stabilizing atmospheric greenhouse gas concentrations, terrestrial carbon-climate feedbacks, linkages between carbon and other biogeochemical cycles, and connections between physical climate processes and carbon dynamics. The start dates of the positions are July 1, 2020 and 2021. We are interested in dynamic researchers and educators who can establish an externally funded, internationally recognized research program. See http://www.ees.rochester.edu for more information about the EES Department. The University of Rochester is a highly ranked research university, and the Rochester area's cultural, educational, and recreational assets frequently place it among the best places to live, work, and raise a family in the United States. Applicants should submit materials via: https://www.rochester.edu/faculty-recruiting. Materials include a curriculum vitae, select reprints, statements of research and teaching goals, and the names and contact information of four references. The review of applications will begin December 20, 2018 and will continue until the positions are filled. The University of Rochester has a strong commitment to principles of diversity and, in that spirit, actively encourages applications from groups underrepresented in higher education. EOE/ Minorities/ Females/ Protected Veterans/ Disabled

Tenure-Track Faculty Position in Environmental Biogeochemistry

The Department of Earth and Environmental Sciences at The University of Texas Arlington invites applications for a tenure-track faculty position in broadly construed areas related to environmental biogeochemistry at the level of Assistant Professor. Faculty candidates for higher ranks with exceptional track records will also be considered. We seek a broadly-trained biogeochemist who complements the interdisciplinary nature of our geology and environmental science programs. While candidates from all sub-disciplines of earth and environmental sciences are encouraged to apply, we are particularly interested in candidates with expertise in analytical biogeochemistry, biogeochemical data mining, climate and biogeochemical dynamical or statistical modeling, or the exposome. Opportunities for collaboration exist with departmental research groups (https://www.uta.edu/ees/) and other research groups of data science, analytical chemistry, ecology, and genomics in the College of Science. Our geochemistry analytical strengths include the on-campus Shimadzu Institute for Research Technologies (http://www.uta.edu/sirt/).

Applicants should have a doctoral degree in earth and environmental sciences or a related field. Successful candidates are expected to demonstrate a commitment to diversity and equity in education through their scholarship, teaching, and/or service. We are deeply committed to increasing diversity and especially encourage applications from women and minority scholars.

Review of applications will begin immediately and continue until the position is filled. For full consideration, applications should be submitted by November 16th, 2018. Applicants must apply online at https://uta.peopleadmin.com/postings/7068.A complete application includes: 1) curriculum vitae, 2) summary of current and proposed research (max. two pages), 3) statement of teaching interests (max. one page), and 4) names and email addresses of three references.

Question regarding this position may be directed via email to Dr. Max Hu, Search Committee Chair (maxhu@uta.edu) or Dr. Arne Winguth, Department Chair (awinguth@uta.edu).

As an equal employment opportunity and affirmative action employer, it is the policy of The University of Texas Arlington to promote and ensure equal employment opportunity for all individuals without regard to race, color, religion, sex, national origin, age, sexual orientation, gender identity, disability, or veteran status.

Positions in Physical Hydrogeology and Paleontology: University of Wisconsin-Milwaukee

The Department of Geosciences at the University of Wisconsin-Milwaukee seeks to fill two positions beginning August 19, 2019: one in Physical Hydrogeology and the other in Paleontology/Paleobiology.

The first position is for a tenure-track faculty position in Physical Hydrogeology (Position # 28007) at the rank of Assistant Professor. Applicants must hold a Ph.D. in hydrogeology (or appropriate related field) at the time of appointment, and have demonstrated research experience in physical hydrogeology. Postdoctoral experience is desirable. The successful candidate is expected to conduct an active, internationally recognized, externally funded research program that will attract and support graduate students. The successful candidate will teach an undergraduate/graduate course in physical hydrogeology, an introductory course, upper level undergraduate and graduate level courses in their field of expertise, and advise graduate student thesis projects.

The second position is for a visiting assistant professor position in Paleontology/Paleobiology (Position # 28018). The position is for 2019-2020 but may be renewed for up to two more years. The successful candidate is expected to develop a vigorous, externally funded research program, teach three courses per year at multiple levels within our curriculum, and supervise research by graduate and undergraduate students. Minimum qualifications for the position are a PhD in Paleontology (or appropriate related field) at the time of appointment and research experience in paleontology/paleobiology. Postdoctoral experience, publications and published abstracts, funding experience, and teaching experience, though not required, are viewed as an asset.

Review of applications will begin December 11, 2018. To guarantee that your application will be reviewed, please submit your application by December 11th. The position remains open until filled. Candidates will upload a cover letter, curriculum vitae, and statement of teaching philosophy and research interests. They will also submit three e-mail addresses for letters of recommendation online. Candidates should also submit three examples of published work uploaded with the application in the following Application Document areas: Publication 1 in 'Other Document 1', Publication 2 in 'Other Document 2', and Publication 3 in 'Other Document 3'. Any applicant wishing to submit additional documents for consideration, including additional published works, should upload those submissions to Application Document areas 'Reference Letter 1' and 'Reference Letter 2'.

The University of Wisconsin-Milwaukee is a Research 1 institution located on the north side of Milwau-

kee. The department of Geosciences offers B.S./B.A., M.S., and Ph.D. degree programs and is staffed by 10 full-time faculty. The University of Wisconsin-Milwaukee is an Equal Opportunity/Affirmative Action Employer.

For more details on how to apply, please visit http://jobs.uwm.edu/postings/search (positions 28007 and 28018). If you have any questions, please contact Shangping Xu (xus@uwm.edu), Physical Hydrogeology Position Primary Contact; Lindsay McHenry (lmchenry@uwm.edu), Paleontology Position Primary Contact; or John L. Isbell, Department of Geosciences Chair (jisbell@uwm.edu).

Assistant Professor, Hydrogeoscientist – West Virginia University Department of Geology and Geography (Job No. 09825)

The West Virginia University Department of Geology & Geography invites applications for a tenure-track position in geology at the Assistant Professor level starting in August 2019. A Ph.D. or equivalent degree in Geoscience or a broadly related field is required at the time of appointment. We seek applications from individuals with interests in basic and applied aspects of water science. The successful applicant will possess demonstrable expertise applicable to competitively funded research problems. Relevant specialties might include physical hydrogeology; fluid flow modeling; hyporheic or vadose zone processes; groundwater-surface water interaction; flow in fractured media; hydrogeology of energy-related activities; groundwater supply and sustainability; contaminant transport; watershed dynamics; ecohydrology; or karst hydrogeology.

Candidates will be evaluated based on their potential to establish a vigorous externally funded research program, publish scholarly work, mentor graduate students, and to teach at the undergraduate and graduate levels, including a junior-senior level physical hydrogeology course.

Research on fresh water resources is a strategic focus at WVU, as demonstrated by a newly established interdisciplinary Institute of Water Security and Science (https://iwss.wvu.edu/), a National Science Foundation funded multi-state Appalachian Freshwater Initiative (https://iwss.wvu.edu/projects/appalachian-freshwater-initiative), and many other water focus areas located in WVU colleges and centers.

WVU (http://www.wvu.edu) is a comprehensive land-grant university that enrolls 29,000 students. It is classified as 'highest research activity' by the Carnegie Foundation. WVU is located in Morgantown (https://www.morgantownwv.gov/), ranked as a most preferred small city in America. The immediate region has a diverse population of about 200,000 residents. The community lies within a high technology corridor that includes several federal research facilities, as well as resource-based industries. The city is readily accessible to Pittsburgh and Washington, DC.

To apply for this position, visit https://careers.wvu.edu, navigate to the position title listed above, and submit (1) a single PDF file including a statement of research interests, a statement of teaching philosophy, and a current curriculum vitae; (2) a list of names and e-mail addresses for at least three individuals who can provide prompt letters of recommendation; and (3) pdf files of up to four publications.

Review of applications will commence on December 3, 2018 and continue until the position is filled. For additional information, please see http://pages.geo.wvu.edu/hydrogeo or contact search chair Steve Kite at steve.kite@mail.wvu.edu. WVU is an EEO/Affirmative Action Employer and welcomes applications from all qualified individuals, including minorities, females, individuals with disabilities, and veterans.

Ocean Sciences

Postdoctoral Scholar Employee

The Marine Physical Laboratory at the Scripps Institution of Oceanography at UC San Diego is seeking a Postdoctoral Scholar Employee in the Air-Sea Interaction Laboratory led by Professor Ken Melville and Dr. Luc Lenain.

Qualifications:

- Recent PhD in Physical Oceanography or related field, including engineering
- Strong background in fluid mechanics

Applications must be submitted to Ken Melville at kmelville@ucsd.edu and Luc Lenain at llenain@ucsd.edu with the following:

1. Curriculum vitae;
2. Personal statement of experience and career goals;
3. Three professional references (name and email)

Postdoctoral Research Associate in Ice shelf/Iceberg-Ocean interaction

The Atmospheric and Oceanic Sciences Program at Princeton University, in association with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks a postdoctoral researcher or more senior position to investigate the physics of ocean interactions with ice shelves and icebergs using numerical models.

Research questions include the role of large calving events in the climate system, influence of ice-ocean interactions on properties of water formation, importance of icebergs representation in climate models,

etc. The models are designed for climate studies which provide the overarching context for the research.

The prospective candidate should have a strong background in one or more areas among physical oceanography, numerical methods, glaciology, sea-ice dynamics and geophysical fluid dynamics. Experience with developing numerical models will be advantageous in this research.

Ph.D. required in either applied mathematics, physics, oceanography, cryosphere, or a related field. Initial appointment is for one year with the possibility of renewal subject to satisfactory performance and available funding.

Complete applications, including a CV, a statement of research interests, and contact information of 3 references should be submitted by November 1st, 2018 11:59 P.M. EST for full consideration. Applicants should be submitted online to https://www.princeton.edu/acad-positions/position/8941.

For more information about the research project and application process, please contact Alistair Adcroft (aadcroft@princeton.edu), Olga Sergienko (osergien@princeton.edu). This position is subject to the University's background check policy.

Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Planetary Sciences

Research Space Scientist–AST, Planetary Studies

The Science & Exploration Directorate, Solar System Exploration Division, Planetary Geology, Geophysics, and Geochemistry Laboratory (Code 698) is seeking a scientist to conduct research into the dynamics of Ocean Worlds and Icy Worlds in our and other solar systems.

The applicant will formulate research plans and hypotheses and develop a novel or complex research approaches for studies of long-term equilibrium dynamics for tidally active ocean worlds (Enceladus, Europa, Ganymede, Callisto, and Titan) as well as potential ocean worlds (e.g., Triton, Pluto, Ceres), developing implications for habitable environments on these planets. The applicant would also perform a comparative planetology approach to link ocean world research to broader research on other bodies such as the Moon, Io, exoplanets, and Early Earth.

The research will involve studying the origin, composition, structure, and evolution of the bodies of the solar system such as the planets and their satellites, asteroids, meteorites, and comets and comparisons to relevant terrestrial analogs where appropriate. Duties may also include playing a leading role in mission development for future planetary exploration.

The applicant will plan research that represents a systematic attack on problems recognized as difficult and unyielding to investigation and will independently conceive and propose for research support to address problems of broad scope and complexity requiring subdivision into separate phases; analyses data and interprets results. The science research results will be shared through publication in requirements documents, or professional papers, invited talks and seminars, and presentations at scientific conferences.

The applicant is expected to serve as support for the development of approaches for conducting investigations of ocean worlds and planetary bodies where geophysical processes can be linked to ocean worlds. Provides significant contributions for current and future mission development, operations, and subsequent data analysis.

Apply at https://www.usajobs.gov/

Space Physics

Assistant Professor JOB #12560, School of Earth and Space Exploration, Arizona State University

The School of Earth and Space Exploration (SESE) at Arizona State University invites applications for a full-time tenure-track faculty position in astrophysics at the assistant professor level. Anticipated start date is August 2019. We seek applications from observers and theorists working in any astrophysics-related discipline. We are especially interested in candidates working on the formation of structure and/or evolution of stars and galaxies during the era of cosmic dawn and reionization, or physics of the Universe, or on the deep characterization of exoplanets, exoplanetary atmospheres, and habitability, but all candidates are encouraged to apply.

The essential duties of the position will be to conduct research in astrophysics, publish in appropriate high-quality journals, provide quality teaching and mentoring in our undergraduate and graduate programs, and participate in appropriate professional service.

Established in 2006, SESE is the focal point of Earth and space science at Arizona State University, one of the most dynamic and fastest growing institutions of higher learning in the United States. An essential part of SESE's mission is to make new discoveries by promoting interdisciplinary science and by integrating science and engineering. SESE faculty and their research groups benefit from a variety of state-of-the-art facilities including high performance computing, access to the 2x8.4m Large Binocular Telescope, 6.5m MMT telescope, 6.5m Magellan telescopes and a host of 2m-class telescopes owned and operated by the State of Arizona. ASU is also a founding member in the Giant Magellan Telescope. Additional resources are available, and we encourage broad, transdisciplinary collaborations between SESE astronomers, planetary scientists, Earth scientists, and engineers (see, http://sese.asu.edu/people/sese-faculty).

Minimum qualifications include: (1) a Ph.D. or equivalent in astronomy or astrophysics, planetary science, or related discipline; (2) a strong research record in astrophysics established through publications in international peer-reviewed journals; and (3) a commitment to quality teaching and mentorship at the graduate and undergraduate levels.

Desired qualifications include a demonstrated track record or strong potential for: (1) conducting externally funded research; (2) teaching existing SESE astronomy courses and mentoring SESE undergraduate and graduate students; (3) working with underserved students or communities; (4) leading and participating in collaborative research efforts; and (5) using cutting edge techniques in spectroscopy, the time domain, data science, or other relevant analysis methods for astrophysics.

SESE brings together Earth and space science into one school, breaking traditional disciplinary boundaries to investigate the biggest questions. SESE combines the strengths of science, engineering, and education, to set the stage for a new era of exploration. See http://sese.asu.edu for more information, and https://sese.asu.edu/about/opportunities/faculty-positions.

To apply, please submit: 1) a cover letter not more than 3 pages long that includes a description of the applicant's research and teaching interests and experience; 2) a current CV; and 3) the names, addresses, email addresses and telephone numbers of three references. All materials should be submitted in PDF format to sesenewfac@asu.edu.

Reference Job #12560 in all correspondence.

The application deadline is December 1, 2018; if not filled, reviews will continue weekly until the search is closed. A background check is required for employment.

Arizona State University is a VEVRAA Federal Contractor and an Equal Opportunity/Affirmative Action Employer. All qualified applicants will be considered without regard to race, color, sex, religion, national origin, disability, protected veteran status, or any other basis protected by the law.

https://www.asu.edu/aad/manuals/acd/acd401.html

http://www.asu.edu/titleIX/

Postcards from the Field

Dear Science Enthusiasts:

Springtime is almost over here in the Great Basin of North America, but up at 3,000 meters everything is still green, thanks to recent, intrusive low-pressure systems. Sage, grasses, and countless wildflowers light up the mountain landscape. Here is senior U.S. Forest Service scientist Connie Millar contemplating a much more senior and very healthy *Pinus flexilis* (limber pine) near the crest of the Diamond Mountain range in Nevada. These "island" populations of conifers dot the widely separated mountain ranges in this high-desert region, still holding secrets of climate and biogeography for adventurous scientists to tease out.

Cheers!

—Scotty Strachan, University of Nevada, Reno (Twitter @ScottySci), 16 June 2018

View more postcards at *http://americangeophysicalunion.tumblr.com/tagged/postcards-from-the-field.*

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